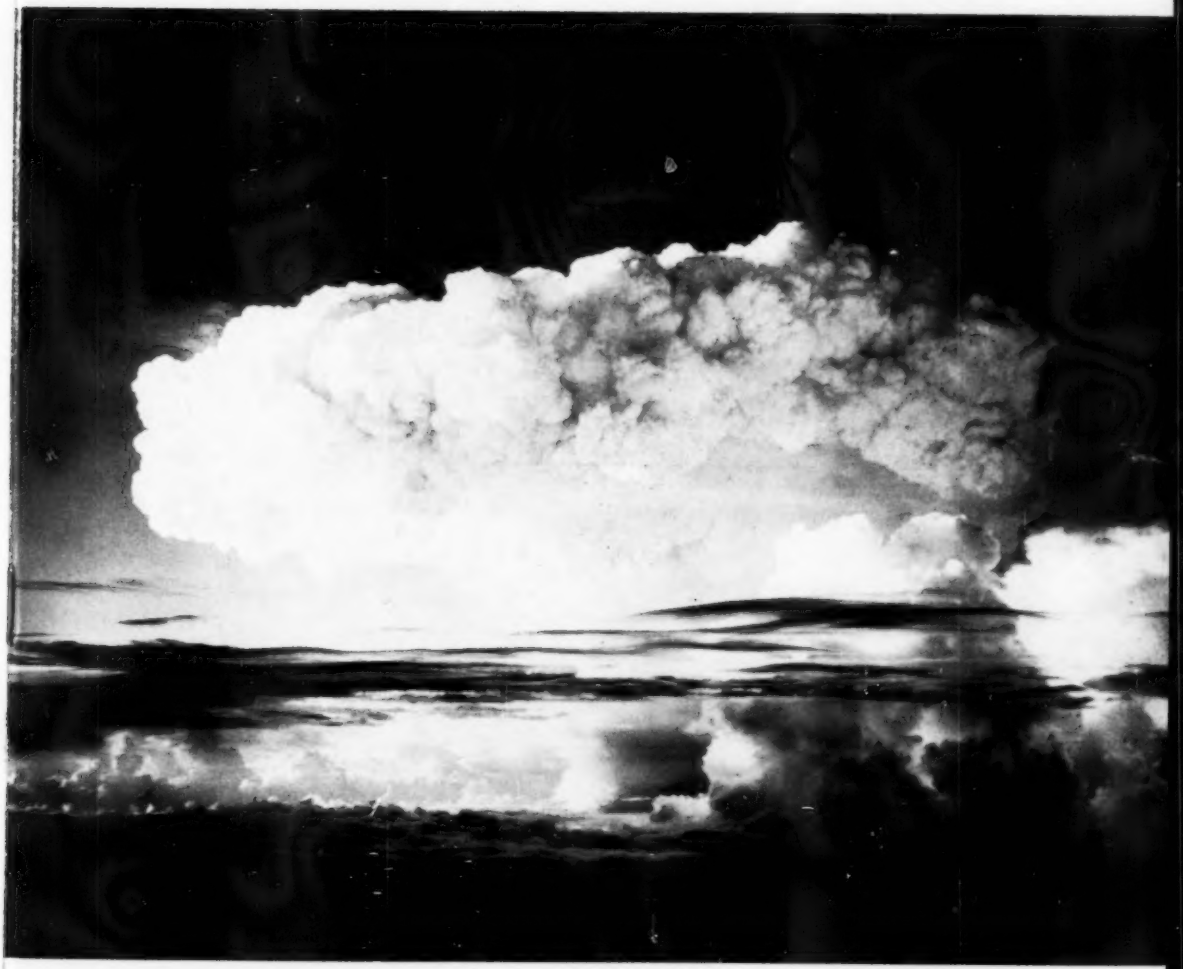
Weatherwise



Volume 10, Number 4 August 1957

"SOME PEOPLE ARE WEATHERWISE BUT MOST ARE OTHERWISE"—BENJAMIN FRANKLIN

WEATHERWISE

THE MAGAZINE ABOUT WEATHER

DAVID M. LUDLUM, *Editor* HENRY W. BULKLEY, *Associate Editor*

Statement on Weather Forecasting

THE Council of the American Meteorological Society has assumed responsibility for issuing periodic statements on scientific aspects of meteorology that are of current concern to the general public. The statement on weather modification appeared in the June issue of *Weatherwise*. The following statement was approved by the Council and released by the Society on 1 July 1957:

Because of the potential value of weather forecasts to the economy of the nation, the American Meterorological Society believes that a statement outlining the forecasting capabilities of the profession should be made available to the American public.

Weather forecasts prepared in some detail are possible for two or three days in advance. The reliability of the prediction, however, decreases progressively after the first day. Forecasts of the weather expected three to seven days in advance must be issued in less specific terms than the shorter range predictions and are ordinarily restricted to a statement that the temperature will be higher or lower than normal for that time of year and that predominantly dry or wet weather will prevail. It is also possible to say with some degree of reliability whether or not the latter part of the period will be significantly warmer or cooler, wetter or drier, than the first part.

For periods of one week to one month in advance, the average temperature and total precipitation for the period can be compared with the normal temperature and precipitation

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Front Cover: The spectacular cloud resulting from the first thermonuclear explosion at the AEC's Proving Ground in the Marshall Islands in autumn of 1952. Photograph was taken at approximately 12,000 ft. altitude about 50 miles from detonation site. After 10 minutes the cloud reached its maximum height, 25 miles, and had spread out over 100 miles.

WEATHERWISE is published bimonthly for the American Meteorological Society. Office of publication, 3 Joy St., Boston 8, Mass. Subscription is $4.00 per year; add 50 cents for postage to Canada and all countries in the Pan-American Postal Union; add $1.00 for all other foreign countries. Subscription orders, claims for missing numbers, changes of address, and advertising correspondence should be addressed to the society at 3 Joy St., Boston 8, Mass. Editorial offices: Box 216, Princeton, N. J.

The author at left discusses fallout patterns with Dr. W. W. Kellogg at recent hearings before the joint Senate-House Committee on Atomic Energy. Wide World photo.

A Survey of the Fallout Forecast Program in the United States

CHARLES K. SHAFER, *Radiometeorologist, Federal Civil Defense Administration, Battle Creek, Michigan*

THE detonation of thermo-nuclear devices differs from the explosion of conventional-type weapons, primarily in the almost point source concentration of millions of tons of TNT energy equivalent, and secondarily in the release of nuclear radiation. The thermal radiation and blast phenomena resulting from such detonations constitute by far the greater portion of the energy released and this energy is essentially expended over a period of a few seconds. However, the nuclear radiation which constitutes perhaps 10 to 20 per cent of the total energy released by the detonation is not completely expended during the first few seconds. This nuclear radiation which is composed of gamma rays, neutrons, alpha particles, and beta particles is rather arbitrarily classified as initial or prompt radiation if it occurs during the first minute and as residual radiation if it occurs after the first minute.

Initial radiation is comprised primarily of the prompt neutrons and high-energy gamma rays resulting from the fission process and the radio-active capture of neutrons. Residual radiation is composed primarily of low-energy gamma rays and beta particles emitted by the fission products and alpha particles emitted from non-fissioned nuclear bomb material such as uranium or plutonium. The emission of this residual radiation from mixed fission products continues for several years undergoing decay at an exponential rate. This paper will deal primarily with the transport of residual, radio-active debris in the atmosphere as it is affected by the general circulation.

When a thermo-nuclear device is detonated at or near the surface of the earth, millions of tons of earth material are pulverized, liquefied, evaporated, and sucked up into the nuclear cloud to elevations sometimes as high as 80,000 feet. As this gaseous and solid material cools, the microscopic radio-active particles from the fission products and other bomb fragments adhere to and coalesce with

the condensed earth material. The earth material is not necessarily in itself radio-active, but rather acts as a carrier to transport the microscopic, radio-active particles back to the surface of the ground. Figure 1 taken from "Fallout and the Winds" (1) indicates the coalescence of earth and radio-active particles. These particles vary in size from approximately 10 microns to 450 microns in diameter (2). Under the influence of gravity these particles fall back to the surface of the earth, the larger particles settling to the ground rapidly, the smaller more slowly. The term "fallout" is used to describe this process by which nuclear produced radio-active particles fall back upon the earth from the upper-air.

In addition to the force of gravity the settling particles are carried by the existing winds in the layers through which they fall. In accordance with the aero-dynamic law for intermediate particle size, a 120 micron spherical particle with a density of 2.5 gm/cm^3 requires approximately 7 hours to fall through 80,000 feet of atmosphere, while a 60 micron particle requires about 22 hours to fall the same distance. Consequently, these particles are under the influence of the wind for many hours and may be carried for several hundred miles from the point of detonation. The Atomic Energy Commission reported that fallout from the 1 March 1954, Castle Bravo detonation extended in significant amounts for 220 miles down-wind, seriously contaminating some 7,000 square miles (3). Figure 2 from "Fallout and the Winds" indicates how various wind combinations affect the paths of radio-active particles in their fall through the atmosphere (1).

Radiation emitted from fallout is of lower

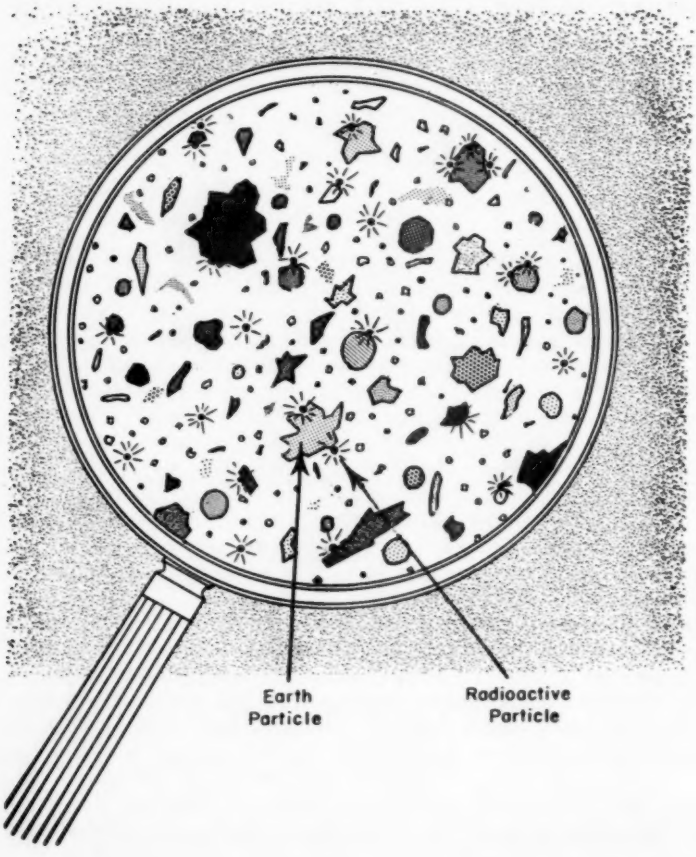


FIG. 1. A magnified view of the coalescence of earth and radio-active particles of a mushroom cloud. FCDA photo.

penetrating power than that from the initial radiation produced at the time of bomb detonation. However, the residual gamma activity has sufficient energy to deeply penetrate body tissues with significant deleterious effects, and beta particles can also cause serious skin damage. According to FCDA Technical Bulletin 19–1 (4), "Less than 25 roentgens * of whole body exposure to gamma rays over a brief space of time will not result in obvious injury. Doses of about 100r will produce nausea and vomiting in some individuals, but will not seriously affect the working efficiency of a group. About 400r would probably prove fatal to some 50 per cent of people so exposed. 600r or more would probably be fatal." Consequently, for war purposes thermo-nuclear weapons provide an additional strategic "pay-off" in the form of fallout which has the potential of seriously affecting the lives and well-being of millions of our civilian population.

Early in 1954 the Federal Civil Defense Administration was apprised of the fallout effects resulting from the surface detonation of the multi-megaton Castle Bravo nuclear device and soon thereafter requested the U. S. Weather Bureau to determine whether a systematic method could be developed to issue routine fallout forecasts on a national basis. As a result the Weather Bureau, under FCDA Delegation No. 3 to the Department of Commerce, was assigned the responsibility for preparing and issuing currently, as well as in an emergency, forecasts and estimates of areas likely to be covered by fallout as a result of enemy attack—such information to be made available to Federal, state, and local civil defense authorities for public information. Furthermore, the Weather Bureau was assigned the responsibility for conducting research which would lead to improved methods of fallout forecasting.

Accordingly, on 1 June 1955, the Weather Bureau established a twice-daily national fallout forecast program designed primarily to meet the civil defense operational requirements for 70 critical urban target areas of the United States. This program utilized the observations of 32 of the GMD-type rawin stations in continental United States. However, since attacks upon bases of military retaliation were equally as likely to occur, the program was expanded on 1 February 1956 to take this probable occurrence into account. Fifty-two of the rawin observatories in continental United States, two in Alaska, and one in Hawaii were utilized for this expanded operation.

Upon a civil and military target basis this network was adequate for operational purposes. However, it was not adequate to account for enemy bombing errors or enemy aircraft diverted or shot down by the Air Defense Command which might result in a nuclear detonation occurring anywhere in the United States or along likely approach routes. Furthermore, because of the high probability of fallout spreading into the United States from surface nuclear detonations in southern Canada, it was necessary to make arrangements with the Government of Canada for

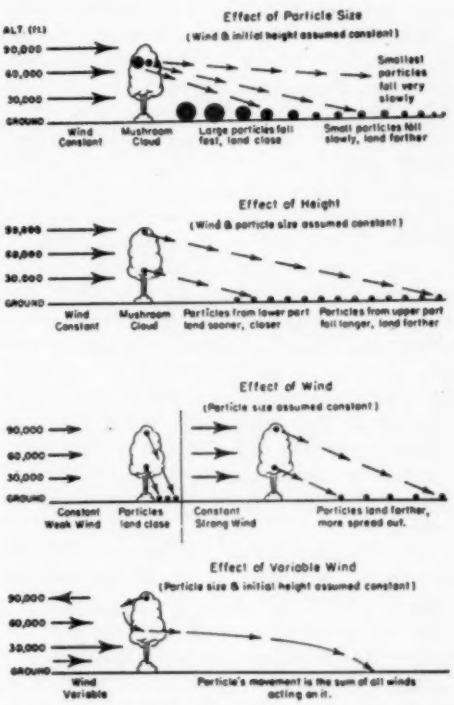


FIG. 2. The effects of particle size, height, constant wind, and variable wind on fallout from cloud.

* Unit of radiation—that amount of X or gamma radiation which produces one electrostatic unit of charge of either sign in one cubic centimeter of air at standard temperature and pressure.

the cooperative twice-daily exchange of fallout forecasts. Consequently, on 24 September 1956, the network was expanded to utilize 68, virtually all, rawin observatories in the United States, eight in southern Canada, two in Alaska, and one in Hawaii. Figure 3 indicates the distribution of the continental North American rawin observatories which participate twice or four times daily in this program.

These fallout transmissions are not forecasts in the strict meteorological sense since they are merely adaptations of rawin observations converted for civil defense uses in terms of direction and horizontal distance out from ground zero for a three-hour period of transport of nuclear debris. Rather than using sample winds at standard levels of the atmosphere and assuming these winds to persist over a finite thickness, the actual position of the balloon in time and space is used to indicate the position on the ground to where particles of fallout are likely to drift originating from that particular altitude. In other words, it is assumed that the rising balloon integrates the net effects of the winds in the layer through which it rises and its path delineates the mirror image of the route of fall which particles of a certain size would assume. From this, one can compute fallout winds which might be looked upon as resultant or integrated winds acting on the entire spectrum of particle sizes from a given height all the way to the ground. Consequently, observed winds at all levels from the surface up to the terminating point of the observation (80,000 feet if possible) are integrated and utilized to indicate the areas which are expected to be affected by fallout, and the arrival time of the radiological debris subsequent to the detonation. Since the only factor involved is the observed or forecasted winds, the fallout forecasts may be issued routinely in peace time as well as in an emergency.

The Weather Bureau utilizes extrapolation techniques in order to extend observational data to 80,000 feet when the actual observation is terminated prior to the time that the balloon reaches this elevation. Basically it is believed that if the balloon attains a minimum altitude of 30,000 feet an adequate sampling of the ambient flow conditions has been made so that the observed data may be extrapolated to the desired altitude. Statistically, approximately 75 per cent of the rawin observations in the United States attained the desired 80,000 feet or greater required during the summer of 1956—therefore, extrapolation methods normally were used in about 25 per cent of the cases.

Usually when the observations did not attain 80,000 feet, the average termination level was near 60,000 feet and extrapolation methods were most frequently used for only the upper 20,000 feet of the atmosphere. However, it should be noted that methods have been developed to extend these observations to the desired 80,000-foot elevation when only 30,000 feet of actual observation has been accomplished. If the observation terminates below 30,000 feet, no fallout forecast is issued. If a minimum of 30,000 feet of observation but not as much as 80,000 feet of observation is attained, the most recently observed rawinsonde data during the preceding 24 hours is added to the adjusted terminal point of the current observation; and if data to 80,000 feet are not available during the preceding 24 hours, seasonal climatological data on a selected area basis (19 in U. S.) are added to the terminal point.

It should be noted that an intermediate step is utilized to extrapolate observations to the 40,000-foot level if the observed data reaches 30,000, but not as high as 40,000 feet. In these cases, the wind observed at the terminal point of the observation (30,000-foot elevation or higher) is assumed to persist to the 40,000-foot elevation and then high level wind data from a recent observation or from seasonal climatology is added to the computed 40,000-foot data as outlined above. This intermediate step more adequately accounts for the effects of the jet stream when the observation terminates below the jet level (usually 35,000 to 40,000 feet in the United States). This technique may appear to be of questionable accuracy, but experience indicates that the net resultant wind effects are predictable within acceptable limits of tolerance if the atmosphere can be sampled up to elevations of 30,000 feet or greater. A recent technical paper by Dr. Adam B. Kochanski of the Air Weather Service, "Wind Variability to 120,000 Feet" (AWS TR 105–142) (5), indicates that the extrapolation methods employed in this fallout forecast program are highly acceptable.

Obviously, in the wintertime when the general atmospheric circulation is more vigorous, the balloon-borne rawin transmitter is blown beyond the limiting angle of radar surveillance more frequently than in the summertime. Consequently, in the wintertime there are fewer observations which attain the desired 80,000 feet of altitude, requiring extrapolation methods to be applied to a greater number of cases than that reported above for the summer months of 1956. During the winter of 1955–56, with GMD type equipment, the average height of the rawin observations in the U. S. was 75,700 feet utilizing 800 gm. balloons and 58,000 feet utilizing 500 gm. balloons. Of the former 800 gm. balloon type, 47.3% reached 80,000 feet, 67.4% reached 70,000 feet, and 85.9% reached 50,000 feet. Of the latter 500 gm. balloon type, 17% reached 80,000 feet, 43.5% reached 70,000 feet, and 59.7% reached 50,000 feet.

It should be noted also that at the present time FCDA is sponsoring a project within the Weather Bureau to provide immediate improvement in accuracy and maximum altitude of upper winds data within the limitations of the present observing system, develop new techniques which can be implemented in the immediate future, and determine the feasibility of radically new systems.

In order to determine the reliability of these forecasts, a comprehensive verification program has recently been undertaken by the Weather Bureau (6) of the first year's forecasts, verifying the forecasts for time variations against observed wind data 6, 12, 18, and 24 hours subsequent to the time of issuance of the forecasts. The findings reveal that the present twice-daily forecasts will indicate the quadrant in which the axis of most intense deposition or the "hot line" will be found with an accuracy of 91%; and if these forecasts were issued each 6 hours in lieu of 12, this accuracy improves to about 98%. If the area is narrowed down from a quadrant to a 40° sector, the present forecasts can indicate this smaller 40° sector 75% of the time; and again, if forecasts were issued each 6 hours, the verification increases from 75%

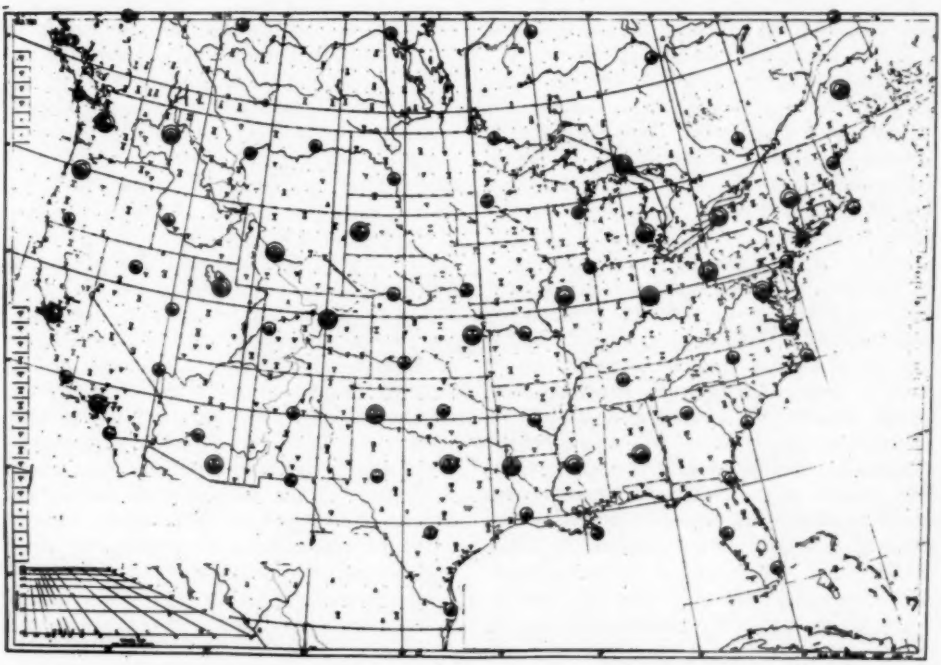


FIG. 3. The upper-air sounding stations which make up the fallout forecast network. Larger symbols make four observations daily; the smaller, two.

to slightly over 90%. In meteorological terms, the 80,000-foot integrated vector or "hot line" will remain within plus or minus 45° 91% of the time for a 12-hour interval and 98% of the time for a 6-hour interval. In order to obtain this increased accuracy, the next step in the development of the fallout forecast program was to expand to four forecasts per day, so on 1 June 1957 26 of the 68 rawin observatories in the United States began issuing fallout forecasts four times daily. These 26 stations, which are located in the areas of greatest population and industrial density, are indicated by the double circles on figure 3.

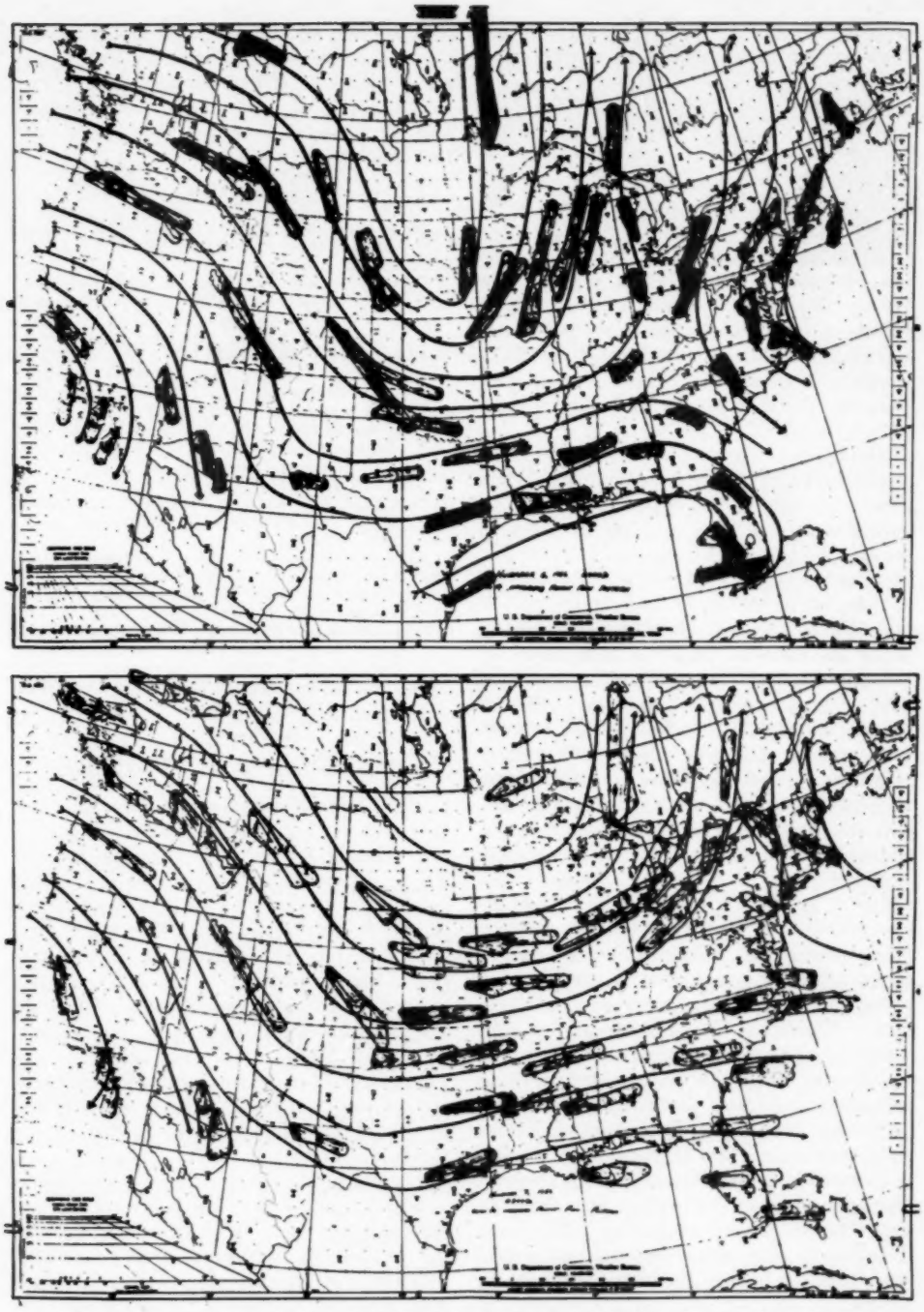
During the Turk Shot of the Teapot Series in Nevada in 1955 the fallout spread in a direction 180° opposite to that which was indicated by an observation taken eight hours prior to detonation. For kiloton size weapons such as are tested in Nevada, this indicates that during an 8-hour period there was a complete directional shift in the integrated winds up to 40,000 feet. The experts at the test site were aware of this radical and rapid shifting of the winds as a result of subsequent observations taken prior to detonation time. However, in order to be completely aware of such radical wind changes, the Weather Bureau has adopted an emergency plan to obtain current fallout forecast data in the event of an impending attack upon our country. In its emergency mobilization plans the Weather Bureau has issued instructions to all of its radar-wind observers to take immediately a special high-level wind observation in the event of a threatened attack and to transmit a special fallout forecast message with triple "Z" priority over our national teletype service, such action to be followed up each six hours as long as the emergency exists. Therefore, if a warning time of as much as 90 minutes is available prior to attack, current fallout forecasts on a national basis will be issued which are no more than one hour old.

Although these forecasts indicate with a high degree of reliability the areas which would be affected by fallout, it should be emphasized that they do not indicate the levels of radiation which might be anticipated. Area forecasts depend only upon the winds in the layers through which the debris falls. Intensity forecasts depend upon not only the TNT blast yield of the weapon, but more importantly upon the radiological or fission product yield of the weapon, as well as the integrated winds and further complications such as the occurrence of precipitation, topographic shielding, etc. Our Government has no way of knowing in advance of an attack the size weapon an enemy would pattern to each of our target areas nor do we have a quick and ready method of assessing how clean or how dirty this weapon is even immediately after detonation. Without this information it is impossible to make intensity forecasts in terms of r per hour or in terms of an integrated dose. This quantitative information can only be obtained as a result of thorough radiological monitoring, or from a combination of limited monitoring and meteorological techniques.

Instructions for decoding the messages and constructing the fallout plots are contained in FCDA's Advisory Bulletin No. 188 and Supplements (7). In the event of a nuclear attack upon the country these forecasts would be used by civil defense to alert areas of the expectancy of fallout and its anticipated time of arrival and to conduct radiological monitoring activities more efficiently.

In order to provide direct meteorological consultation and training to civil defense, FCDA through the Weather Bureau has assigned meteorologists to each of its Regional and National Offices, and has round-the-clock meteorological briefing service at its National Headquarters in Battle Creek. Among other details these meteorologists twice daily prepare a three-dimensional kinematic analysis of the integrated wind vectors over the United States from 80,000 feet to the surface of the earth and from 40,000 feet to the surface of the earth. The former indicates the location of the "hot line" or axis of most intense radiological deposition on the surface of the earth for megaton weapons and the latter for kiloton weapons. This type of analysis indicates the instantaneous variations of 3-dimensional flow in space; and in those cases where streamlines of the integrated vertical winds undergo pronounced horizontal shear, a material improvement is made over forecasts based upon a single station analysis.

Furthermore, these deep-layer, three-dimensional analyses are quite conservative in the meteorological sense over short periods of time, and the troughs and ridges can be successfully prognosticated by standard extra-



FIGS. 3–4. Charts show the integrated fallout flow pattern at 80,000 ft. Vectors show the predicted "hot-line" downwind. Upper chart for 0300 GMT, 6 November 1956; lower chart 24 hours later.

polation methods for 12 to 24 hours. Thus, both time and spatial variations can be taken into account to provide forecasts for the emergency period after the initial attack when the availability of high level wind data might become extremely limited. Figures 4 and 5 are examples of these three-dimensional analyses with the fallout areas as derived from the fallout forecasts.

To assist civil defense offices in long-range survival planning, FCDA requested the Weather Bureau to undertake a climatological survey of fallout probabilities in continental United States, the Territories, and southern Canada. Consequently, under special contract the Weather Bureau undertook a comprehensive survey of five years of wind data to elevations of 80,000 feet at 51 points, constructed almost 100,000 fallout areas from these wind data, and tabulated probability occurrences by machine methods in order to provide the information requested. This survey has been completed and is in the process of being published by FCDA.

A second step or refinement is currently under way narrowing down the first survey by utilizing a 6-hour transport of the integrated wind effects from 70,000 feet to the surface of the earth, with the assumption that this net or integrated effect will define the "hot line" or area of intense deposition for megaton size weapons. The result of this survey will indicate the likelihood or probability of getting a severe or intense radiological fallout condition.

Under Section 2 of FCDA Delegation No. 3, the U. S. Weather Bureau is also given the responsibility of preparing analyses of past data, conducting research, and developing techniques and capabilities leading to improved forecasts of radiological fallout patterns. Within the Weather Bureau this delegation of responsibility has been assigned to the Special Projects Section under the most competent leadership of Dr. Lester Machta. At present his staff is engaged in experimentally programming the fallout forecast project for computer methods to be used in conjunction with the prognoses of the Joint Numerical Weather Project at Suitland, Maryland. The plan is to program for time and spatial variations for periods up to 36 hours in the future.

FCDA's fallout forecast program has been in effect for approximately two years and to date it has undergone three modifications. Continuous research is being maintained in many phases of fallout phenomenology, and as the results of these studies become available the fallout forecast program will be further modified accordingly.

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HURRICANE WATCHERS

Two new mobile weather stations, designed for use during hurricanes, were put into operation recently by the U.S. Weather Bureau. These self-sufficient land cruisers will be manned by two weather observers, who may be called upon to report weather every hour during the day and night to the hearest hurricane forecast office.

Each of the mobile weather observing units is built in a 10-foot parcel delivery type body on a truck chassis. All doors, windows, and joints have been sealed for waterproof protection, and tie-down facilities are provided to anchor the trucks during hurricane-force winds.

The trucks are equipped with a wind speed indicator; a wind direction and wind gust recorder; a microbarograph; an aneroid barometer for pressure readings; a battery aspirated psychrometer for measuring temperature and humidity; and equipment for measuring rainfall. Each unit is equipped with a radio receiver and transmitter.

The author charts the past and ponders the future.

Weather Forecasting in Transition— A Survey and Outlook

JEROME NAMIAS, *Chief, Extended Forecast Section, U. S. Weather Bureau*

(Transcribed from an address presented at a Symposium, "Meteorology: An Outlook for the Future," held 30 April 1957 in Washington, D. C. at a Joint Session of the American Meteorological Society and American Geophysical Union.)

A LITTLE over two years ago, at a symposium on problems of meteorology sponsored by the National Academy of Sciences, the central theme was the ever timely subject of weather prediction. During the course of this symposium and the ensuing discussion a number of comments by speakers and audience indicated a divergence of opinion as to the future roles of electronic computers and conventional forecasters. The optimistic end of the broad spectrum of opinion is indicated by the memorable comment of a famous meteorologist that he was "turning in his union card as a synoptic meteorologist," the application of another short-range prognosticator for employment in long-range forecasting because he felt the hot breath of the machine. Incidentally, his dilemma was not alleviated when someone told him that extended forecasting was but a temporary refuge. On the pessimistic end were the small group who felt that machine methods were doomed to failure as were many earlier objective systems.

Now, two years later, we are discussing the same problem but apparently from a more realistic standpoint. I think it has now become clear even to the most stubborn pockets of resistance that numerical forecasting has proved itself of value to the forecaster and offers the greatest possibility of advance in weather forecasting in its entire history. At the same time the imperfections and limitations of numerical forecasting are more clearly apparent, and the great difficulties of further advance following the initial breakthrough are now realized.

Weather forecasting is thus in a state of transition—a transition from subjectivity to objectivity; from art to automation. In view of the painfully slow progress along these lines in past generations it is no exaggeration to claim that some sort of revolution is in the making.

Numerical forecasting has come about largely through three factors: (1) greatly increased data in three dimensions, (2) better physical knowledge of how the atmosphere works, and (3) the availability of high speed computing facilities. As far as short-range prognosis is concerned, Dr. Cressman, in the preceding paper, has aptly summarized the current status so that I shall not dwell on this phase. However, as an impartial observer, I should like to comment on the present success of operational numerical prognoses. These opinions arise from routine and direct use of the end products in extended forecasting work. Actually, objective and automatic use of the short-range numerical prognoses is now routine in extended forecasting work. The great-

est advance, and a tremendous one, has come about in ability to predict the 500-mb patterns at 48-hour range. As you know, barotropic predictions are carried out to 72 hours. While 24-hour predictions are good, it is possible to obtain approximately equal skill by standard forecasting techniques, so that the additional assistance obtained from the 24-hour numerical prognosis is small. The 72-hour prognoses are still imperfect because of rapid deterioration of the barotropic prognosis with time, as to render them of little use, and other techniques can probably achieve better results. In the 48-hour range, however, the short-range forecaster's mental processes become inadequate. He can, for example, cope with extrapolation or subjective considerations of vorticity flux up to about 24 hours, but beyond he usually cannot compete with the machine. Forty-eight-hour numerical prognoses are now certainly as good as, and I believe better than, any subjectively produced product. This achievement probably represents the greatest advance in forecasting in the past ten years and raises hopes for further gains in numerical weather prediction.

Numerically produced sea level prognostic charts are as yet quite inadequate so that experienced forecasters can apparently do better. In order to improve the sea level prognoses, it will be necessary to make more effective use of numerically produced upper level prognoses, since our fund of knowledge on which to base such prognoses has about come to a standstill after progress of the past ten or fifteen years.

The Extended and Long-Range Picture

As a participant, I view the extended and long-range picture through eyes of a biased observer. It appears that substantial progress has been made in the preparation of 5-day forecasts during the past few years. In the first place, there is much greater objectivity in the preparation of these forecasts. This is indicated, for example, in the training of Air Force officers who, in 90-day courses in extended forecasting, are able to prepare reasonably skillful 5-day forecasts. Secondly, there is increased ability in predicting the series of daily maps making up the 5-day means. About 5 or 10 years ago along with others, I had doubts about man's ability to ever specify the day-to-day weather systems for 5 or 6 days. Certainly, even today no one should plan a picnic on the basis of such forecasts. Nevertheless, the types and lines of synoptic activity that are estimable are useful for many purposes. In other words, concentration on this problem of interplay between short-range and extended scale systems has led to improvements.

Other gains in extended forecasting involve the ability to predict more elements and for distant areas. Predictions of Arctic meteorological conditions, of patterns favorable to high pollution concentration, and of conditions favorable to the genesis of severe storms are now possible.

Thirty-day outlooks have shown definite skill over the simple use of climatological probabilities, and have enjoyed higher skills in the past year or two. Predictions for sea level pressures and prevailing winds are now made routinely for assistance to Navy Hydrographic work. It is not only possible to predict with some success the persistence of patterns, the like of which produce drought, but it is also possible at times to foresee great changes in regime like the break of a drought. Of course, these predictions are yet far from reaching the desired reliability. Other elements now predicted are the prevailing tracks of cyclones and anti-cyclones from the mean predicted circulation. A vast amount of work has led to this development, and indicates that the life history of cyclones and anti-cyclones is implied by the mean circulation pattern for the relevant month. Furthermore, certain types of storms are not likely unless the basic mean pattern has the proper characteristics permitting development. It is also possible to estimate from these prognostic means such things as total monthly degree days. Some small success has been attained in predicting areas of vulnerability to hurricanes and even tornado activity. At present such estimates are probably too general in scope to be of much practical use however, and much more research remains to be done along these particular lines. Perhaps the greatest contribution of extended forecasting research and practice in the past twenty years has been in pioneering and bringing to the fore concepts which short-range forecasting has now adopted. Although methods

(Continued on page 140)

Fluctuations in Frequency of Tropical Storms

EMANUEL M. BALLENZWEIG, *Extended Forecast Section, U. S. Weather Bureau, Washington, D. C.*

THE hurricane is a vagary of nature that leaves a profound impression on any who have witnessed the awesome devastation it can wreak. The destructive nature of these storms has been recorded since the voyages of Columbus who encountered hurricanes on his travels to the New World. However, what little is known of the periodic variations in the frequency and intensity of hurricane vortices has been gained during the past seventy years or so. During that period we have seen that our hurricane climate is highly variable. Of course, we have no right to assume that it is stable, as the earth's climate is constantly changing (as pointed out in recent articles in *Weatherwise*).

People, though, are accustomed to thinking in terms of average conditions: the average temperature, the average precipitation, etc. The concept of average conditions, which is often referred to as the normal, freezes one to an unchanging climate. The public thinks of "normal" as the usual state, but mathematically this term refers to the arithmetic mean of a large number of years. Normals can, therefore, be misleading if large changes take place within the period of years constituting the normal, if there is no preferred frequency, or if there is a change in the observing techniques.

The normal annual frequency of tropical storms in the North Atlantic area (the Atlantic Ocean, Caribbean Sea, and Gulf of Mexico) is approximately eight,* but a glance

* These statistics are based upon the latest set of data gathered by the Office of Climatology, U.S.W.B. in cooperation with the Extended Forecast Section, and the Hurricane Forecast Centers in Miami, New Orleans, and San Juan. See page 132.

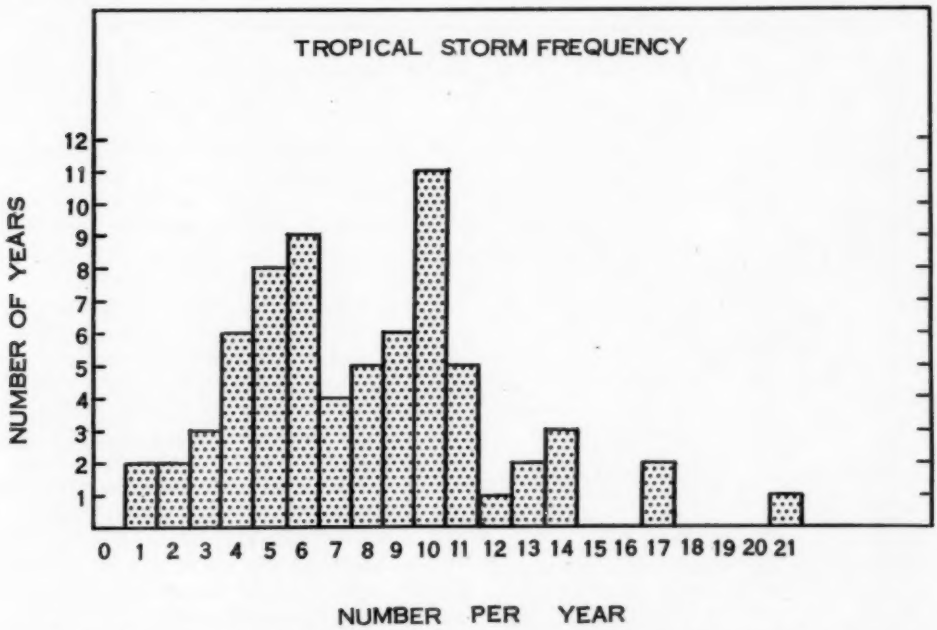

FIG. 1. Frequency distribution of annual totals of tropical storm occurrences in the Atlantic area from 1887–1956. Ten storms per year, the most frequent annual total, is observed eleven times during the seventy-year period. Also note that five and six storms a year occur almost as often as ten.

at figure 1 shows a bimodal distribution of hurricane frequency—six storms a year is about as ordinary an occurrence as 10 and both of these frequencies are much more usual than the average value of eight. A frequency distribution such as this is not uncommon in meteorology; this particular one is associated with the secular trends in tropical storm activity observed in the past seventy years, 1887–1956 (fig. 2).

The bimodal character of the histogram (fig. 1) is associated with the low level of tropical storm occurrence in the years 1894–1930 contrasted with the remaining years in the sample. The mean of the first group of 37 years is 6 storms per year in contradistinction to the mean for the remaining sample of 33 years which is 10 storms per year.

The ultimate cause of these longer period fluctuations is still a matter of conjecture; in fact the mystery of the year-to-year fluctuations is still far from solved. They may be related to solar influences, to changes in the constituents of the earth's atmosphere, or to changes in the temperature of the sea surface; but no one can deny that they are related to the fluctuations in the general circulation.

For many years it has been recognized that the paths of tropical, as well as extratropical, cyclones are strongly influenced by the prevailing state of the general circulation, the storms tending to be steered in the direction of the broad-scale flow in the mid-troposphere. Routine 5-day and 30-day forecasting experience in the past 15–20 years, numerous case studies, and a recently inaugurated research project on this specific problem have yielded many more details about the role of the large-scale circulation in influencing the generation and the motion of tropical cyclones.

A study of the relationship between the broad-scale circulation and seasonal frequencies of North Atlantic tropical storms showed well-marked differences between seasonal circulation patterns in years of frequent tropical cyclone activity as contrasted with years of infrequent occurrence. The dominating features of the planetary circulation during these two regimes can conveniently be studied by the height departures from normal (often referred to as height anomalies)

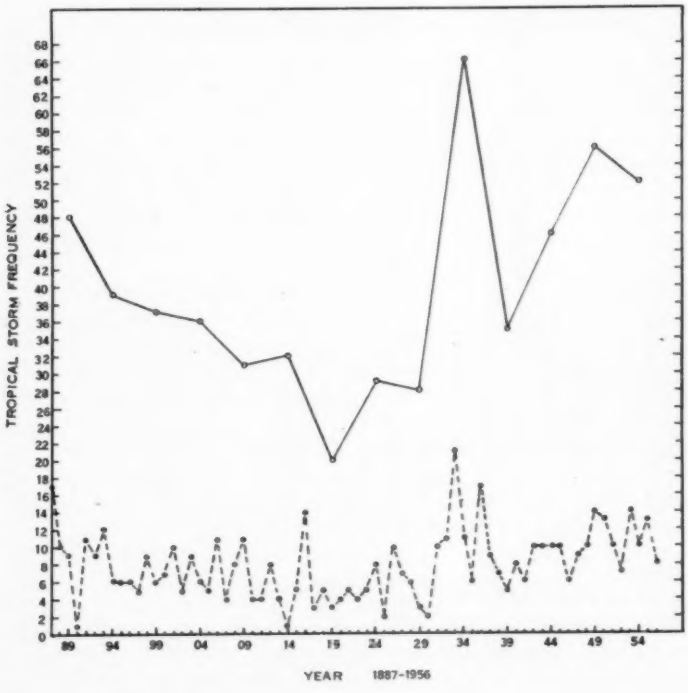

FIG. 2. Variations in tropical storm frequency in the North Atlantic. Dashed curve is the annual frequency of tropical storms; solid curve connects values of 5-year totals of tropical storms, i.e. 1954 totals 1952–56.

of the 700-mb pressure surface, a level where the flow is representative of that in the mid-troposphere. The circulation at this level is usually in the form of open waves in a circumpolar current; the height anomaly converts these waves into individual vortices. These height anomaly patterns are a representation of the flow relative to the normal. The anomalous component of flow around a positive area can be likened to the motion around an anticyclone—clockwise in the northern hemisphere; the flow around a negative area is counterclockwise as around a cyclone.

Figure 3 shows the charts of average 700-mb height anomalies for those 5 seasons (August–October in the period 1933–1955) with maximum tropical cyclone formation in the entire North Atlantic and the average height anomalies for those 5 seasons with minimum formation. The anomaly patterns differ considerably over the Atlantic area. In the years of maximum frequency positive anomalies are extensive across the entire Atlantic near latitude 40°N while negative anomalies prevail near Iceland and in subtropical portions of the Atlantic and Caribbean. These negative anomalies in the subtropical oceanic areas apparently provide a favorable climate for tropical storm formation, as the extensive area within which hurricane genesis occurs is one in which the pressure is relatively low. In years of minimum frequency there is also an area of positive anomaly in the Atlantic, but it is located farther to the south close to latitude 30°, while an elongated negative anomaly area stretches eastward from the Great Lakes region to the central Atlantic and negative anomalies prevail near the British Isles depressing the westerlies southward over the Atlantic.

These differences reflect the fact that the westerlies, the subtropical ridge, and the subtropical easterlies are farther north in years of maximum tropical storm activity than in years of minimum activity. This is what one might expect from the normal relationship of tropical storm activity to the latitude of the westerlies (fig. 4); i.e. tropical storm frequency reaches its peak in late summer and early fall when the westerlies are farthest north. The seasonal northward displacement of the westerlies is associated with a similar shift of the subtropical easterlies. Equatorwards of the subtropical jet stream is a current of little vertical wind shear, a condition thought necessary to hurricane genesis. This, too, is shunted north into latitudes where the Coriolis force is sufficiently large * to deflect light convergent drifts of air and thereby initiate cyclonic rotation.

When the westerlies are north of normal, the distribution of the zonal (west-east or east-west) winds is favorable for the shearing of the planetary wave trains and their component parts, the troughs and ridges. With stronger westerly winds in the north, the waves move more rapidly than in the

* The consensus of opinion among tropical meteorologists is that a certain minimum value is necessary; but a controversy exists as to whether large values tend to inhibit formation.

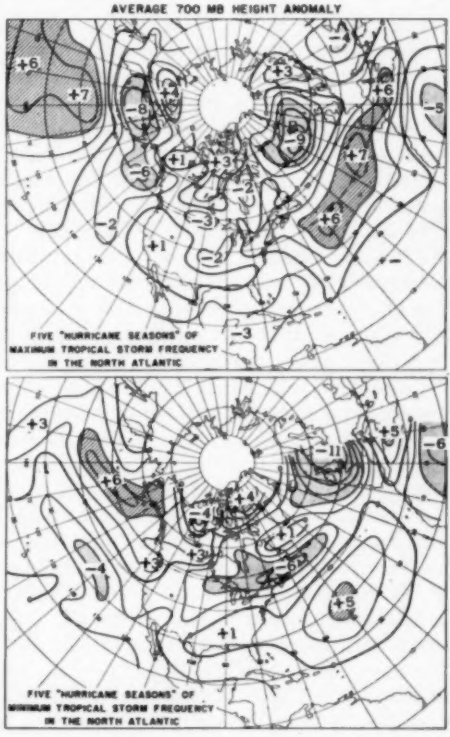
AVERAGE 700 MB HEIGHT ANOMALY
FIVE "HURRICANE SEASONS" OF MAXIMUM TROPICAL STORM FREQUENCY IN THE NORTH ATLANTIC
FIVE "HURRICANE SEASONS" OF MINIMUM TROPICAL STORM FREQUENCY IN THE NORTH ATLANTIC

FIG. 3. Composite charts of the average departures from normal (in tens of feet) of 700-mb height for the five seasons of maximum tropical cyclone incidence (top) and 5 seasons of minimum incidence (bottom) in the North Atlantic. (Hatched areas are where the positive anomalies exceed or equal 40 feet and the dotted areas are where the negative anomalies exceed or equal 40 feet.)

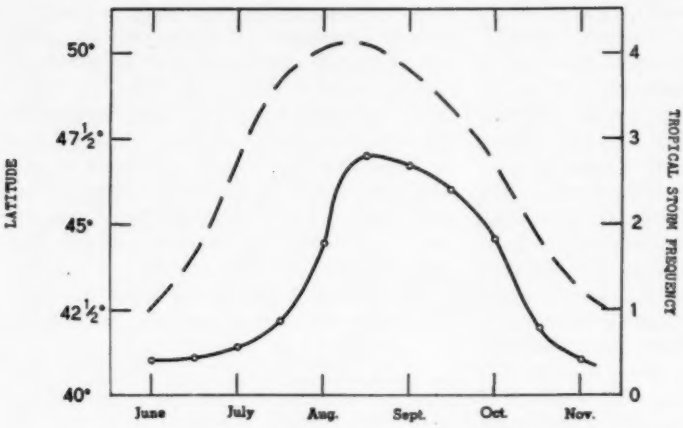

FIG. 4. Comparison of the curve of mean monthly frequencies of tropical storms 1887–1956 (solid curve) and the curve showing a portion of annual course of the latitudinal position of the axis of maximum westerlies at 700-mb averaged around the hemisphere (dashed curve). Note the similarity in the position of the two peaks.

south, resulting in fracturing of the southern portions which sometimes become retrogressive (easterly waves). This relative motion in different latitudes is often associated with the deployment and cutting off of pools of cold mid-tropospheric air in the subtropics. Perhaps both the cold air aloft and the broad generally cyclonic field at the base of an originally extensive trough are favorable to the growth of cyclonic vortices of many scales —including, of course, the hurricane. Thus, broadly speaking, anomalous flow patterns which accentuate the seasonally favorable pattern result in the formation of more tropical cyclones than normal in the Atlantic, while anomalous flow patterns which are more akin to seasonably unfavorable (colder season) patterns result in fewer tropical cyclones than normal.

Circulation patterns associated with high and low frequencies of tropical storm formation for monthly periods are basically similar to the seasonal patterns. For example, a comparison of the circulation of August 1955, which was associated with an unusually high frequency of tropical cyclogenesis (e.g., the memorable hurricanes Connie and Diane), with that of August 1956, when there was a paucity of tropical storm development, shows striking differences in 700-mb height (fig. 5). The heights were higher in 1956 in the polar regions and an extensive girdle of lower heights was manifest in August 1956 at middle latitudes in essentially the areas where below normal heights were a feature of the composite map for few storms (bottom of fig. 3). These height differences were associated with a shift of the hemispheric zonal wind systems southward from August 1955 to August 1956 (fig. 6). This comparative study is evidence which tends to support the relationship described earlier. In August 1956 when the westerlies were south of normal only one tropical storm was observed, while four tropical cyclones (three full hurricanes) developed in August 1955 when the westerlies were displaced north of normal and were weak in a wide band south of about 50°N.

It is, therefore, thought that the composite seasonal circulation patterns shown in figure 3 can be used as guides in making monthly predictions of the frequency of tropical storm formation once the circulation prognosis has been made. In addition to the composite circulation patterns for the extreme frequencies in tropical storm generation, similar patterns have been constructed to serve as guides for specifying which portions of the Atlantic will be the preferred sites of storm formation during the next month and which coastal areas of the United States can expect to have a tropical storm frequency greater or less than their climatological probability.

These guides are applicable only when the predicted circulation anomaly pattern resembles one (or more) of the composites. In 5-day forecasts some indication of expected positions of tropical cyclones is given out on a daily series of prognostic charts. This information is supplied as guidance material to hurricane forecasters and is frequently discussed with them by phone contact. For the

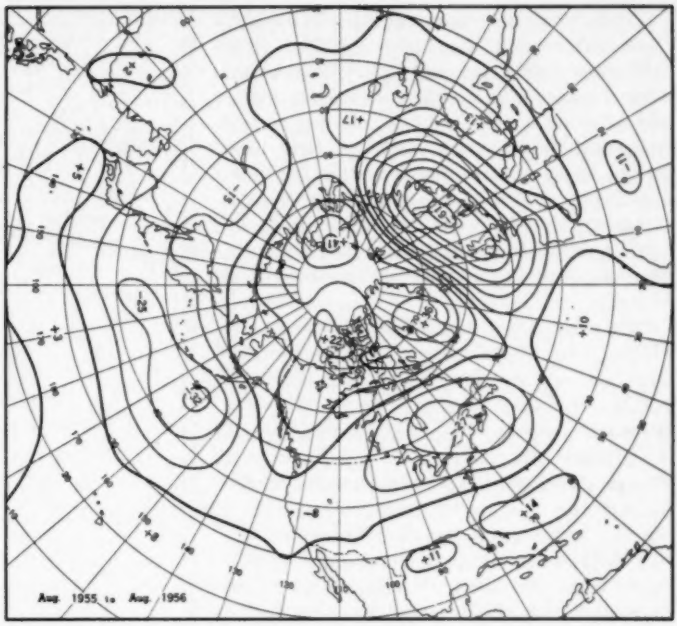

FIG. 5. Mean 700-mb height difference (in tens of feet) from August 1955 to August 1956. The large differences were associated with marked reversal of the general circulation.

past two years the Extended Forecast Section has prepared twice a month, for internal Weather Bureau use, 30-day estimates of probabilities of hurricane formation and of the general vulnerability of coastal areas. The outlooks have enjoyed some success and since mid-June 1957 this information has been released to the public on an experimental basis. These carefully worded probability statements are being prepared by the Hurricane Central in Miami, partly on the basis of these semi-monthly hurricane outlooks and partly on climatological information. Each release states the experimental nature of the outlooks. Of course these outlooks can be no better than the circulation prognosis upon which they are based. It is hoped that the use of high speed electronic computers will lead to improved statistical-dynamical methods of forecasting the circulation regime, and thus also assist in the long-range prediction of hurricane vulnerability.

REFERENCES FOR FURTHER READING

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2. Namias, J., "Long-Range Factors Affecting the Genesis and Paths of Tropical Cyclones." *Proceedings of the UNESCO Symposium on Typhoons,* 9–12 November 1954, Tokyo, 1955, 213–219.
3. Namias, J., "Secular Fluctuations in Vulnerability to Tropical Cyclones In and Off New England." *Monthly Weather Review,* 1955, 83, pp. 155–162.
4. Riehl, H., *Tropical Meteorology.* McGraw-Hill Book Co., New York, 1954, Chapter 11.

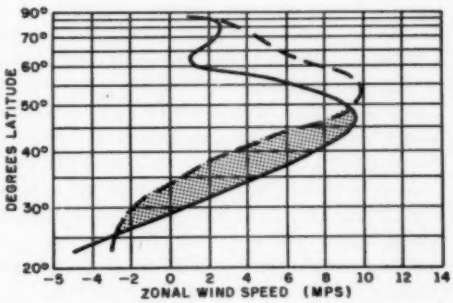
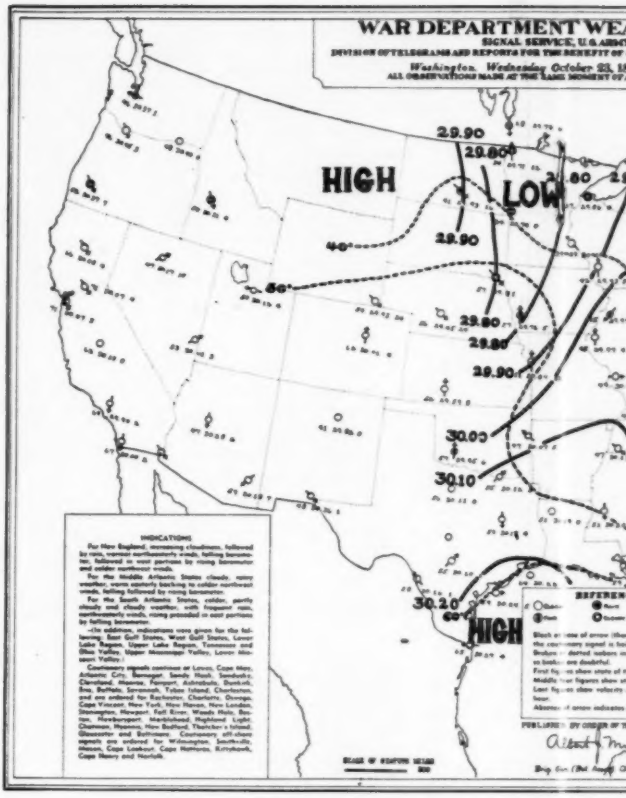


FIG. 6. Mean 700-mb zonal wind speed profiles in the Western Hemisphere for August 1956 (solid line) and August 1955 (dashed line). Note the southward displacement and increase in speed (shaded area) of the hemispheric zonal wind systems from August 1955 to August 1956.

The Middle Atlantic Co
of 22–24 Octobe

ROBERT A. HOOVER, *U. S. Weather Bu*



THIS hurricane, mentioned in Tannehill's list of severe tropical storms in New England, was rather unusual since it remained some distance inland after entering the southern coast of North Carolina and yet caused hurricane winds as far north as New England. Another interesting feature is the great amount of available information on the destruction wrought by this storm. Ordinarily reports would be meager for a storm of such an early date in our recorded meteorological history.

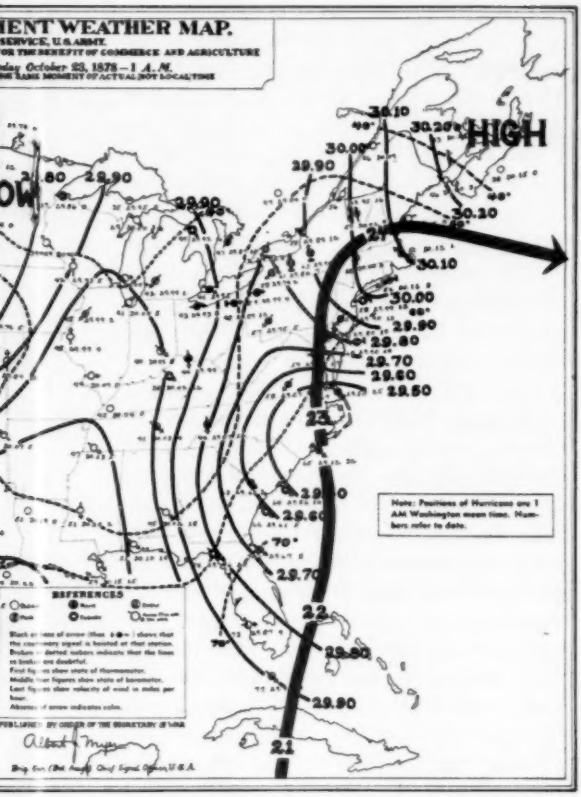
The map shown here is an unaltered copy of the Army Signal Corps weather map for 0100, 23 October 1878, upon which the track of the hurricane, as shown in the *Monthly Weather Review*, has been superimposed. The indications (forecasts) and cautionary signals (wind warnings) were issued on the basis of the data shown on this map.

Little is known of the early history of this hurricane, since the first reports of its existence were contained in dispatches from Havana, Cuba, which stated the effects of a hurricane there on the 21st consisted of heavy rain, much damage to buildings, and the sinking of three schooners. Heavy rainfall was also reported at Key West. There may be some question as to the position of the track in this area—as shown on the map the track is about 125 statute miles east of Havana.

The 0100 weather map for 21 October showed a well-developed ridge of high pressure centered near Cape Hatteras and a trough of low pressure extending from just west of the Great Lakes to northern Texas. By 0100 on the 23rd when the ridge had moved to Nova Scotia, the trough had moved eastward sufficiently to cause the hurricane to assume a more northerly course, and a second ridge had been more firmly established to the rear of the trough. Evidently the hurricane moved north in this trough until it became imbedded in the westerlies over New York State after which it turned eastward across New England.

Along the North Carolina coast the lowest pressure of 984 mbs and strongest wind of 100 mph were reported at the Cape Lookout Signal Corps Station. Apparently the storm lost little of its intensity as it moved northward, for it passed over Washington, D. C., where a calm was reported with a pressure of 975 mbs. A minimum barometer reading of 976 mbs was reported at Annapolis and Baltimore, Maryland. Cape May, New Jersey, clocked a maximum wind of 84 mph and Philadelphia 72 mph. The storm may have diminished somewhat in intensity over Pennsylvania, but even so a maximum wind of 120 mph from the southeast was reported at Mt. Washington, New Hampshire, and the anemometer cups were blown away at Portland, Maine, after which the wind was estimated to have reached 70 mph.

There was considerable rainfall with this



ıtic Coast Hurricane
October 1878

eather Bureau, Washington, D. C.

hurricane as far north as New York State with amounts in North Carolina from 2 to over 4 inches. It was stated at Washington, D. C., that the rain fell there in a continuous sheet for three hours and the wind speed was the highest recorded since observations commenced in 1870. However, the damage in Washington was small considering the intensity of the storm and was confined mostly to the unroofing of houses and the blowing down of fences and trees.

Wind damage was especially severe in Philadelphia where over 700 substantially constructed buildings were either totally destroyed or severely damaged. These included 31 churches, 23 schools, 35 factories and warehouses, 5 hotels, 2 elevators, and 50 other buildings such as depots, ferryhouses, mills, and railroad offices. Two sections of the Reading Railroad bridge fell into the Delaware River—the river being at its highest level in 27 years. Eight vessels were sunk and 22 damaged in the port. It was said that never before was so much damage sustained. Strangely enough, in spite of this damage, there were only seven people reported killed and 75 injured in that city.

At Wilmington, Delaware, the river rose higher than ever before, there were numerous drownings, parts of the city were inundated, 75 houses were wholly or partially unroofed, 15 houses were carried away by the flood, and 6 were blown down.

There was much damage to shipping from Florida to New England—23 schooners were washed ashore on the Massachusetts coast alone. To mention a few, one sailor alone out of a crew of 19 survived, and the ship itself and its cargo were a complete loss when the *A. S. Davis* ran ashore south of Cape Henry, Virginia. It was stated that "the life saving crew did their whole duty but the tempest was so violent that human effort could avail nothing." The steamer *Express* sank in Chesapeake Bay with only three of 28 passengers and crew being saved. The captain was washed overboard and drowned when the *Magnolia* was completely wrecked in Albemarle Sound. On the New Jersey coast, the captain and one seaman were drowned in the wreck of the schooner *Dever*, and four of the crew were lost in the sinking of the schooner *Sarah Clark*. The schooner *Mary Tyce* was wrecked at New Haven, Connecticut, with the loss of 2 lives. In all about 30 steamships and schooners were sunk or wrecked, a much larger number were damaged, and in addition countless small craft were destroyed or damaged.

Tides ran very high as far north as New England where much damage was done by the high water. Off the Virginia coast, Cobb's and Smith's Islands were entirely submerged. All live stock there was swept away by the water which reached its highest peak in 27 years.

Once-in-a-Hundred-Year Rainstorm Washington, D. C., 4 September 1939

BLANCHE B. HULL, *Quartermaster Research and Development Command, Natick, Mass.*

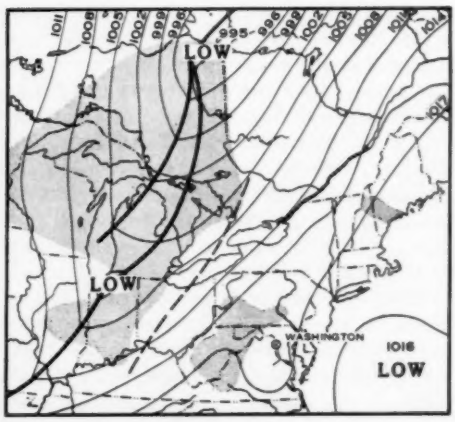
THE most intense 2-hour rainstorm on record in Washington, D. C., occurred in coincidence with the passage of a pre-cold front squall line over the District early in the evening of Labor Day, 4 September 1939. During the two hours of severe thunderstorm conditions more than four inches of rain fell. Later at night, as the surface cold front with comparatively light activity moved over the District, additional rain fell, bringing the total for the storm to 4.49 inches.

SYNOPTIC SITUATION

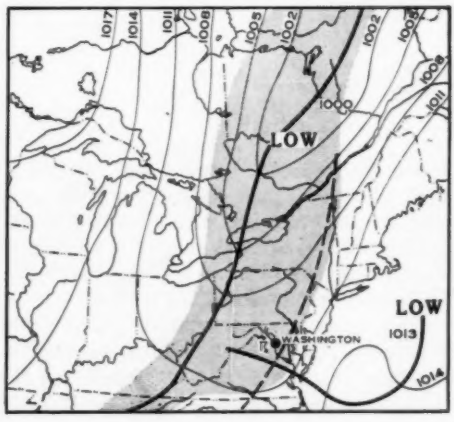
According to the Weather Bureau synoptic map at 0730 EST there was a deep low pressure system north of Lake Huron, with cold front extending through western Indiana and extreme southern Illinois. The upper-air map at roughly 10,000 feet indicated an upper low with trough line extending from north of Lake Huron southward over southern Alabama. A minor disturbance, centered about 300 miles east of the Virginia Capes, was moving northeastward. Pressure was high from Newfoundland and Nova Scotia southward over the ocean, and relatively high and rising from the District of Keewatin southward to Kansas.

The disturbance moved rapidly eastward, precipitating thunderstorms and rain over an area 200 to 300 miles wide from southern Michigan and southern New York State to eastern Tennessee and western Kentucky. At 1330, the synoptic weather map showed the squall line approaching the Appalachian region, about 250 miles in advance of the cold front.

The squall line passed over Washington, D. C. early in the evening of September 4th. Intense rain fell for about two hours between 1900 and 2100. Moderate wind speed characterized the passing of the disturbance. The wind, blowing from the southeast at about 12 mph in the morning and from the south at about 24 mph in the afternoon, shifted to the northwest at about 28 mph at



0730 EST—4 September 1939



1930 EST—4 September 1939

1930 during the squall. Gusts, abrupt wind shifts, and a temperature drop of 15° occurred with the passage of the squall line. Pressure dropped from 30.02 inches at 0730 to 29.68 inches at 1930.

Rain ceased about 2100 at most of the stations, then began again before midnight as the cold front approached. With the passing of the cold front in the hours after 0200 on 5 September, clearing skies, cooler temperature, rising pressure, and a moderate westerly wind prevailed at Washington.

Rainfall Intensities

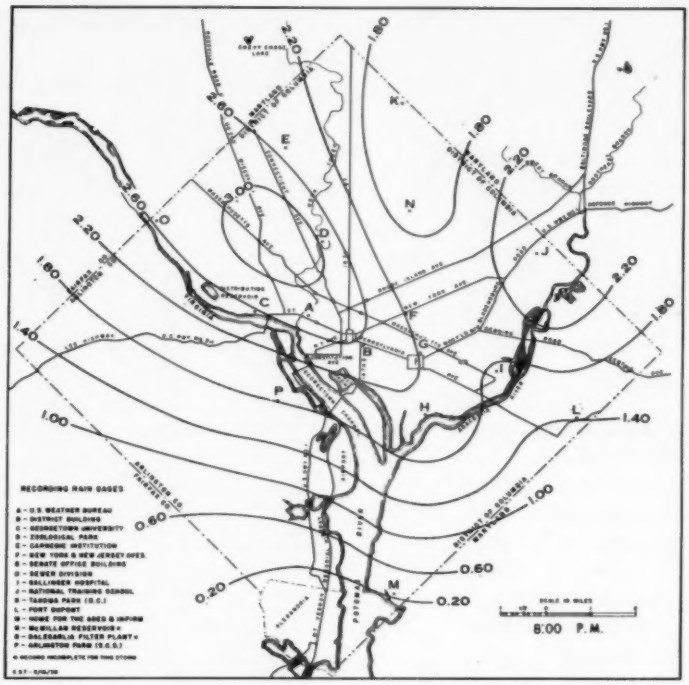
Isohyetal maps of 15-minute accumulation of rainfall have shown the intensity and the path of the storm across the District. The storm fell on 16 automatic recording rain gages, 14 of which were owned and maintained by the District of Columbia at various locations within the 10-mile-square area of the District. The other two gages were the official gage at the central Weather Bureau office and one operated for research purposes at Arlington, Virginia, by Dr. C. W. Thornthwaite, Soil Conservation Service.

The rain began in the northwest outskirts of the District along the Potomac River and was first recorded at 1845 at the Dalecarlia Filter Plant, Conduit Road, and at Carnegie Institute, Broad Branch Road. The rainfall spread rapidly the first 15 minutes, covering about half of the District with 0.10 to 0.40 inches. At 1930 two inches had fallen in the northwest area where it first began raining, and two secondary centers of intensity had developed in the northeast and southeast sections of the District. By 1945 more than 2.00 inches of rain had fallen in the northwest center of intensity and the rain had spread throughout the District. At 2000 over three-fourths of the District had over 1.00 inch of rain, about half having between 2.00 and 3.00 inches. The intense fall continued for another hour without interruption, to give an accumulation of over 4.00 inches of rain by 2100. Rain at some stations began at 1900 or later, and ended after 2100.

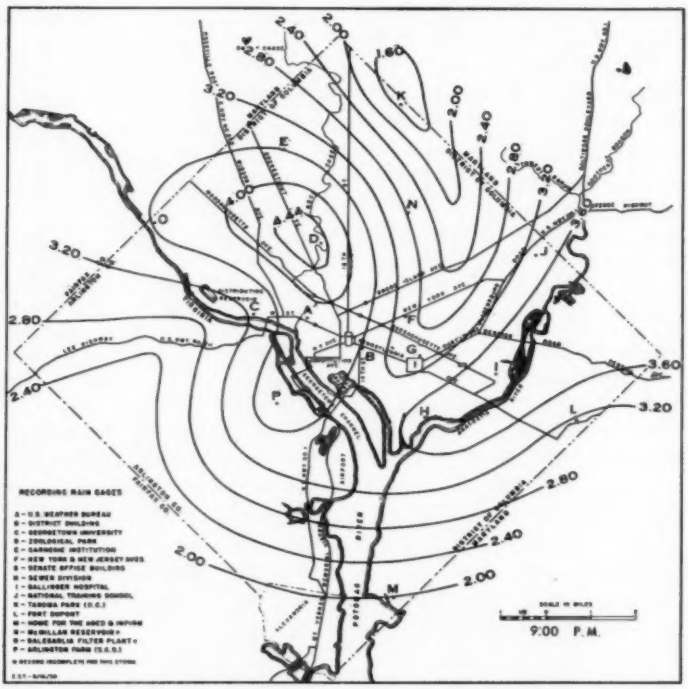
The rate of fall is of interest. Tables of rainfall intensities at Zoological Park and Gallinger Hospital, two of the stations receiving over 4.00 inches in two hours plus a later additional prolonged light rain for about two hours, show the accumulated depth for each time interval and intensity for each 5-minute interval for the entire storm duration. The 0.70 of an inch of rain that fell at Gallinger Hospital between 2030 and 2035, a rate of 8.4 inches per hour, is the highest 5-minute

Rainfall Intensity, Washington, D. C., 4 September 1939
National Zoological Park

Time	Accumulated depth (inches)	Depth for each time interval (inches)	Intensity for each time interval (inches/hour)
6:45	0.00	.00	0.00
:50	.04	.04	.48
:55	.13	.09	1.08
7:00	.20	.07	.84
:05	.28	.08	.96
:10	.40	.12	1.44
:15	.54	.14	1.68
:20	.80	.26	3.12
:25	1.00	.20	2.40
:30	1.34	.34	4.08
:35	1.47	.13	1.56
:40	1.90	.43	5.16
:45	2.30	.40	4.80
:50	2.60	.30	3.60
:55	2.80	.20	2.40
8:00	3.00	.20	2.40
:05	3.14	.14	1.68
:10	3.30	.16	1.92
:15	3.46	.16	1.92
:20	3.70	.24	2.88
:25	4.00	.30	3.60
:30	4.20	.20	2.40
:35	4.33	.13	1.56
:45	4.40	.07	.42
:55	4.41	.01	.06
9:05	4.42	.01	.06
9:25	4.42	.00	.00
:45	4.43	.01	.03
10:05	4.43	.00	.00
:10	4.54	.11	1.32
:15	4.56	.02	.24
:20	4.60	.04	.48
:25	4.62	.02	.24
:30	4.66	.04	.48
:35	4.67	.01	.12
:40	4.68	.01	.12
:45	4.70	.02	.24
11:15	4.70	.00	.00
:25	4.71	.01	.06
:35	4.72	.01	.06



Total rainfall at District of Columbia stations from 1845 to 2000 EST, 4 September 1939.



Total rainfall at District of Columbia stations from 1845 to 2100 EST, 4 September 1939.

MAXIMUM INTENSITIES OF RAINFALL, WASHINGTON, D. C., 4 SEPTEMBER 1939

Location	A	B	C	D	E	F	G	H	I	J	K	L	M	O	P
5 min.	0.38	0.44	0.40	0.43	0.40	0.36	0.40	0.30	0.70	0.30	0.54	0.37	0.32	0.60	0.69
10 min.	.71	.84	.60	.83	.60	.56	.64	.50	1.02	.50	.55	.65	.60	.90	.92
15 min.	.98	1.10	.80	1.13	.84	.76	.86	.70	1.20	.74	.69	.77	.80	1.12	1.12
30 min.	1.61	1.84	1.36	1.76	1.46	1.36	1.32	1.20	1.64	1.32	.76	1.35	1.38	1.64	1.67
60 min.	2.70	2.58	2.24	2.90	2.28	2.60	2.16	2.14	2.90	2.30	1.30	2.38	1.98	2.32	2.45
120 min.	3.84	3.48	2.94	4.14	3.45	3.51	3.00	4.00	4.02	3.18	2.07	3.11	2.95	3.98	4.02

A. 24th and M Streets N.W.
B. District Building, 14th and E Streets N.W.
C. Georgetown University, 37th and O Streets N.W.
D. National Zoological Park
E. Carnegie Institute, 5241 Broad Branch Road
F. New York and New Jersey Avenues N.W. (fire station)
G. Senate Office Building, Constitution and Delaware Avenues N.E.
H. 1st and O Streets S.E.
I. Gallinger Hospital, 19th and C Streets S.E.
J. National Training School for Boys (Bladensburg Road)
K. Takoma Park, front of newspaper office
L. Fort Dupont, Pennsylvania Avenue S.E.
M. Home for Aged and Infirm, Blue Plain
O. Dalecarlia Filtration Plant (Conduit Road)
P. Arlington Farm Evaporation Station (west edge of farm)

intensity on record locally; the 4.14 inches that fell at Zoo Park is the record-breaking rain amount in the District for two hours. It is interesting to note an uninterrupted fall of .20 to .38 inches per 5-minute periods at Gallinger Hospital from 1940 to 2015. Other gages showed sustained rainfall but of lesser amounts, while some showed spurts and lulls in the 5-minute calculations.

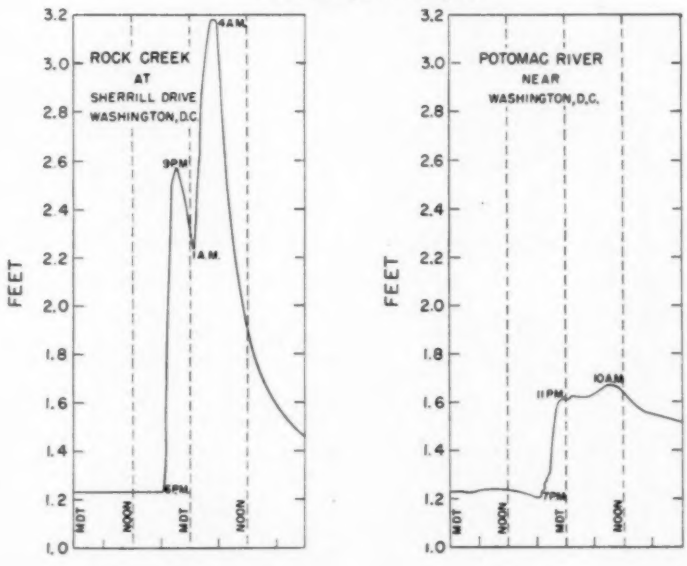
STREAM GAGE RECORDINGS

The Potomac River stream gage, located about 2 miles upstream from Chain Bridge in the general direction of the Dalecarlia Filter Plant, showed an abrupt rise of about 0.4 foot during the storm and a gradual rise for several hours afterward. Mean discharge on the 4th was 2,049 cu. ft. per second and

(*Continued on page 139*)

STREAM GAGE RECORDINGS

SEPTEMBER 4 & 5, 1939



Hurricanes and Tropical Storms 1887–1956

Total number tropical storms*			Total number hurricanes		Loss of life		Damage by categories**	
Year	In all areas	Reaching U. S. coast	In all areas	Reaching U. S. coast	Total all areas	In United States	Total all areas	In United States
1887	17	4	10	3				
1888	10	6	6	4				
1889	9	4	5	2				
1890	1	0	1	0				
1891	11	4	8	2				
1892	9	3	4	0				
1893	12	7	9	5				
1894	6	3	5	2				
1895	6	4	2	1				
1896	6	4	6	4				
1897	5	4	2	1				
1898	9	6	4	3				
1899	6	4	5	3				
1900	7	3	3	1		6,000		7
1901	10	6	3	2		10		6
1902	5	3	3	2		#		#
1903	9	2	8	2		9		6
1904	6	4	2	2		#		6
1905	5	2	1	0		#		#
1906	11	6	6	4		285		7
1907	4	3	0	0		#		#
1908	8	3	5	1		#		#
1909	11	7	4	3		404		7
1910	4	3	3	2		13		6
1911	4	3	3	2		17		6
1912	8	6	5	3		12		6
1913	4	3	3	2		#		#
1914	1	1	0	0		#		#
1915	5	4	4	3		600		8
1916	14	9	11	6		107		7
1917	3	1	2	1		5		5
1918	5	2	3	1		34		6
1919	3	2	1	1		287		7
1920	4	3	4	3		2		6
1921	5	2	4	2		5		6
1922	4	1	3	0		0		#
1923	5	3	4	2		0		4
1924	8	4	5	3		2		3
1925	2	2	1	1		6		3
1926	10	3	8	3		269		8
1927	7	1	4	0		0		#
1928	6	3	4	3		1,836		7
1929	3	2	3	2		3		6
1930	2	1	2	0		0		2
1931	10	3	2	0		0		#
1932	11	6	6	2		0		#
1933	21	6	9	4		63		7
1934	11	5	6	3		17		6
1935	6	2	5	2		414		7

Hurricanes and Tropical Storms 1887–1956—*Continued*

Year	Total number tropical storms*		Total number hurricanes		Loss of life		Damage by categories**	
	In all areas	Reaching U. S. coast	In all areas	Reaching U. S. coast	Total all areas	In United States	Total all areas	In United States
1936	17	8	7	3		9		6
1937	9	4	3	0		0		4
1938	7	4	3	2		600		8
1939	5	3	2	0		3		3
1940	8	4	4	3		51		6
1941	6	4	4	2		10		7
1942	10	3	4	2	17	8	7	7
1943	10	4	5	3	19	16	7	7
1944	10	4	6	3	1,076	64	8	8
1945	10	5	4	3	29	7	8	8
1946	6	4	3	1	5	0	7	7
1947	9	7	5	3	72	53	8	8
1948	10	5	6	3	24	3	7	7
1949	14	4	7	2	4	4	8	8
1950	13	4	11	4	27	19	7	7
1951	10	1	8	0	244	0	7	6
1952	7	2	6	1	16	3	6	6
1953	14	6	6	2	3	2	7	7
1954	10	5	7	4	720†	193	9	9
1955	13	5	10	3	1,518†	218	9	9
1956	8	2	4	1	76	21	8	7
Total	555	261	322	143				
Median	8	4	4	2				

* Including hurricanes.

\# Not reported in literature, believed minor.

† Additional deaths for which figures are not available.

** This is a new form of presentation of storm damage estimates. The Weather Bureau has for some time recognized the fact that without detailed expert appraisal of damage all figures published are merely approximations to fact. Since errors in dollar estimates vary in proportion to the total damage, storms are placed in categories varying from 1 to 9 as follows:

1 Less than $50
2 $50 to $500
3 $500 to $5,000
4 $5,000 to $50,000
5 $50,000 to $500,000
6 $500,000 to $5,000,000
7 $5,000,000 to $50,000,000
8 $50,000,000 to $500,000,000
9 $500,000,000 to $5,000,000,000

Blank spaces indicate no figures available.

(Reprinted from *Weekly Weather and Crop Bulletin*, Special Summary on Hurricane Audrey, July 1, 1957.)

Some Notable Hurricane Tides

(1) Sept. 16, 1875, Indianola, Tex.; disastrous inundation from Matagorda Bay; wind estimated 100 m.p.h.; 176 lives lost.

(2) Aug. 19, 1886, Indianola, Tex.; water in the bay rose rapidly; not a house remained undamaged; the town was not rebuilt.

(3) Sept. 8, 1900, Galveston, Tex.; the water rose at a steady rate from 3 p.m., until about 7:30 p.m., when there was a sudden rise of about 4 feet; approximately 6,000 persons lost their lives.

(4) Aug. 17, 1915, Galveston, Tex.; the tide at Galveston was 12 feet above normal; extreme wind speed was 120 m.p.h.; 275 lives lost; property damage estimated at $50,000,000.

(5) Sept. 29, 1915, Mississippi Delta; highest tides of record (to that time) observed on delta; extreme wind speed was 140 m.p.h.; 99 out of 100 homes destroyed in Leeville; 275 deaths reported.

(6) July 5, 1916, Mobile, Ala.; tide was 11.6 feet above normal; wind reached 107 m.p.h.; 4 deaths and $3,000,000 property damage in Mobile.

(7) Oct. 25, 1921, Tampa, Fla.; tide at Tampa rose to 10.5 feet; 6 deaths and $3,000,000 property damage.

(*Continued on page 139*)

Tornadoes Mark May, and a Hurricane Visits in June

DAVID M. LUDLUM, *Editor*

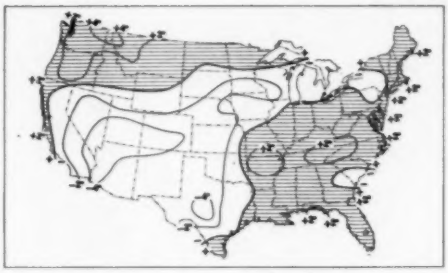
The turbulent behavior of the atmosphere which set the theme of the April weather pattern over the central portions of the United States continued to characterize meteorological conditions during the month of May. The historic drought-breaking rains in the southern Plains, which had commenced in March and continued to spread their liquid gold in April, expanded both their intensity and scope in May. Along with the rains came thunderstorms, hail storms, and wind storms in unprecedented quantities. May recorded more tornadoes than any other single month in the Weather Bureau's tabulation of severe storms which commenced in 1916.

The main features of the mean upper-air circulation maps of April were again in evidence: (1) low pressure over the American Southwest, (2) anticyclonic conditions over western Canada and adjacent Alaska, and (3) a large cyclonic vortex in the Atlantic Ocean south of Greenland. Although there were changes in intensity and minor shifts in location, these prominences on the weather map guided the circulation for our portion of the Northern Hemisphere in May as they had in April.

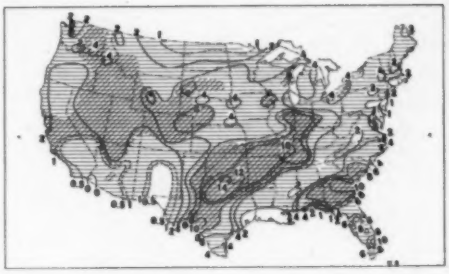
Unlike April, however, when depressions and troughs were the interesting features of the daily weather maps, it was anticyclones and ridges which caught the attention of the weather analysts. A very strong ridge of high pressure extended from the polar region southward to Alaska, and then with lesser intensity reached a long arm southeastward across the Canadian Prairies, the Great Lakes, and the Middle Atlantic States, to join with a stronger than normal Bermuda high in the western Atlantic.

The Arctic high and the Bermuda high were both in ideal situations to make much meteorological mischief in the central valleys of the United States. From western Canada on occasions cool, dry air was drawn southeastward, and alternately it was cool, moist Pacific air that the Arctic high sent into the United States. Both of these streams met air masses of great potential energy flowing up from the warm, moist Gulf of Mexico. Thus, the battle line of air masses in the central valleys was somewhat more extensive than in April, reaching all the way from northern Mexico to western New York State. Along this line paraded cloudbursts, floods, tornadoes, hail storms, and damaging thunderstorms in profusion.

The main storm track of May lay across the central Plains and thence eastward or east-northeastward to the large vortex off Newfoundland. There



Departure of Average Temperature from Normal in degrees Fahrenheit. USWB chart.



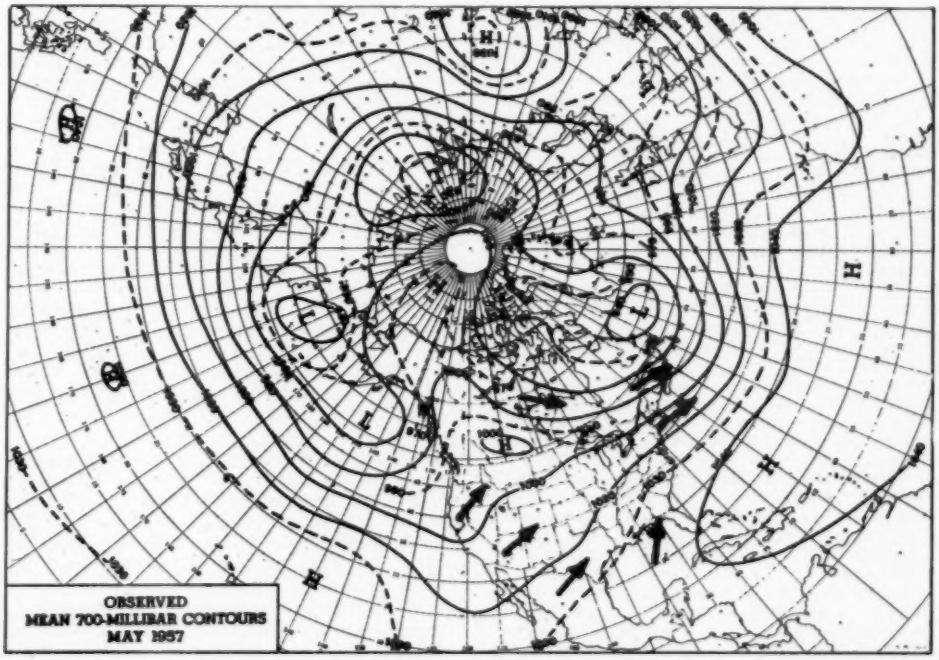
Total Precipitation in inches. USWB chart.

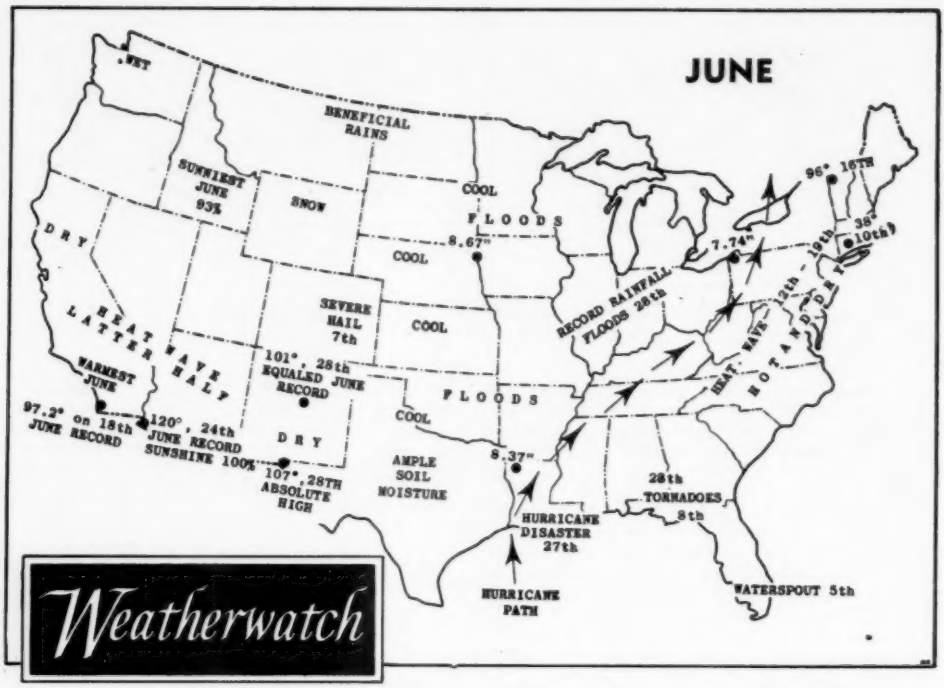
were also two Gulf disturbances which also followed easterly tracks and passed into the Atlantic Ocean. No coastal storms of the northeaster type moved along the middle Atlantic seaboard, depriving the coastal plain from Virginia to Cape Cod of its best source of moisture and aggravating the incipient water shortage in that area of large industrial cities and extensive truck farm operations. Over the northern Plateau and the mid-Pacific Coast trough conditions precipitated quantities of Pacific moisture to make it one of the wettest Mays in history in northern California and Nevada.

A GREAT MAY ANTICYCLONE—The weather maps for the first ten days of May were dominated by the movement of two anticyclones of some note. The first and more important to the weather of the nation made an appearance over the Canadian Yukon on 29 April, from whence it moved slowly eastward to the congenial waters of still frigid Hudson Bay. There it built up a remarkable central pressure for May on the 2nd of the month—1049 mbs. or 30.98 inches. From this position it was able to dominate the circulation pattern of the conti-

(*Continued on page 138*)

The upper-air map below shows the pattern of air flow for January at about 10,000 feet, on which the average weather largely depends. The contours lines represent the mean height of the 700 mb. pressure level. Figures are in tens of feet: 1020 = 10,200 ft., 980 = 9,800 ft., etc. USWB chart.





CIRCULATION—The anticyclonic activity of May over western Canada and Hudson Bay continued as a prominent feature of the early June period. The outstanding anticyclone of the month started southeastward from the Yukon region on the 4th, moved across the Great Lakes on the 7–8th, passed off the New England coast on the 9th, reaching a position south of Newfoundland on the 13th. With ridge conditions persisting over much of southern Canada, a cool air stream fed into the region east of the Mississippi where the first dozen days of June were considerably below normal, causing resort proprietors to fear a repetition of the cool summer of 1956.

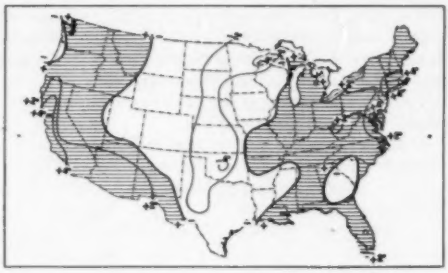
The upper-air circulation, however, underwent a drastic change on the 12–13th to transform the pressure pattern into a truly summer type. A cyclonic vortex established itself in the Hudson Bay area, ending the anticyclonic dominance there which had prevailed since April. A trough trailed south-southwestward from central Canada for the rest of the month, creating favorable conditions for a number of small depressions to form in the upper Mississippi Valley and moved northward.

After the 15th the great Pacific sub-tropical anticyclone built eastward to the southern California coast to intensify the severity of the heat spell there. San Diego set an all-time June maximum on the 18th with a 97° mark. Inland at Needles the mercury soared to 119° and at Yuma to 120°.

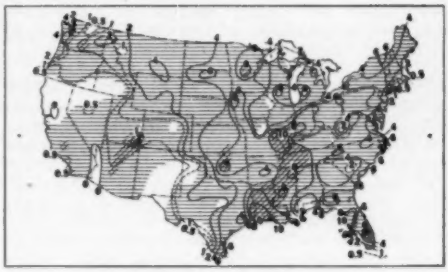
A heat wave of mid-summer proportions over the Eastern States developed on the 12th as the Bermuda high built westward and increased in magnitude. Thus, the familiar squeeze play between the Pacific high jutting in over California and the Atlantic high over the Gulf States was set up. The tightened gradient naturally stimulated the air flow in the central trough with the result that vast quantities of hot and humid air flowed northward from the Gulf into the Ohio Valley and eastward.

ST. LOUIS CLOUDBURST—The state of Missouri, among other claims to fame, holds the U. S. record for the heaviest one-hour rainfall (Holt—12.00″ in 42 minutes—22 June 1947). The terrain is generally low and gently rolling so that orographic influences cannot explain the occurrence of the excessive precipitations such as occurred at Holt or during the month under survey in the St. Louis area.

A glance at the 0130 weather map on 15 June, however, gives a key as to why ten inches or more of rain may fall in that section in a matter of several hours. A very slow moving cold front lay just to the north of St. Louis, extending from southern Lake Michigan to central Oklahoma. The front was running into opposition in its eastward progress from a stronger than normal high over the Atlantic States. The tightened gradient enabled very moist air with nighttime dewpoints above 70° to move into southern Missouri and Illinois. Very heavy rain resulted, and with the front almost stationary the downpours kept up for longer than usual number of hours. In the area around St. Louis and 50 miles to the east and northeast 5 to 10 inches and more fell. The greatest amounts dropped just east of St. Louis



Departure of Average Temperature from Normal in degrees Fahrenheit. USWB chart.



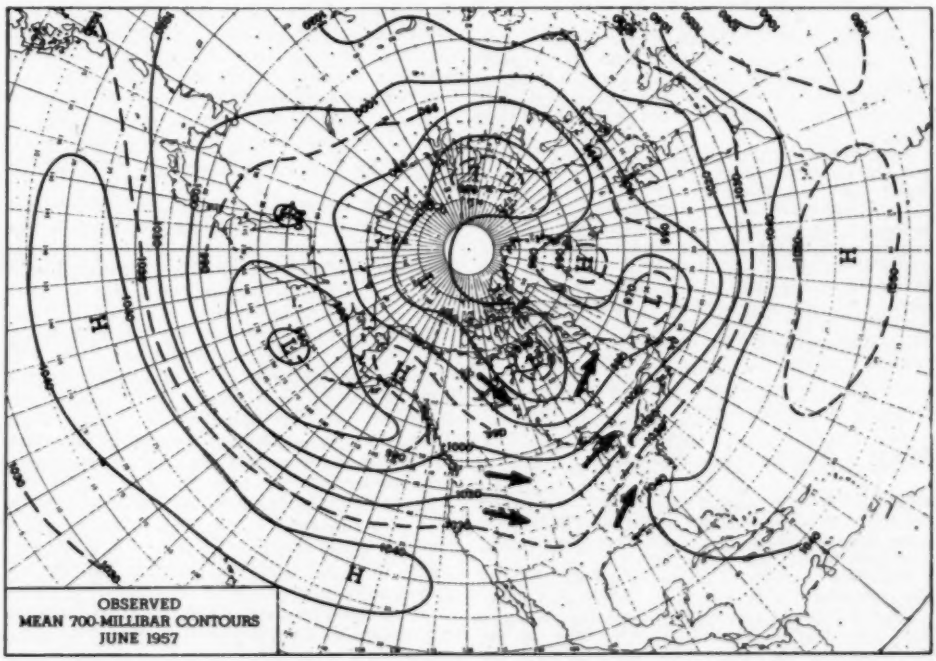
Total Precipitation in inches. USWB chart.

in Illinois with 18.82 inches at Scott Field and 13.75 at nearby Belleville. Downtown St. Louis measured 8.54 and Pacific, Missouri, had 11.75. Serious flooding developed in St. Louis and Illinois with 10 deaths reported in the latter and evacuation of 3,500 persons from their homes necessitated.

EASTERN HEAT WAVE—A real heat wave set in on 12 June when the mercury in Washington National Airport's well-aspirated instrument shelter reached a maximum of 90°. Thereafter, for eight consecutive days the mercury topped 90° each day with readings of 97, 97, 95, and 96 on the 15–18th. This marked the longest June heat wave since the record-breaking 10 days with 90° plus in 1943. The heat spell was broken momentarily as a cold front reached the Atlantic coast about noon on the 19th with less humid air from the northern Plains bringing some relief. The heat pattern soon reestablished itself and Washington had three more 90° days on 22–24 June.

The heat was severe in northern New York State and western New England with readings close to 100°. At Burlington, Vermont, a mark of 96° on the 16th equaled the all-time June maximum for that city of long records. The warm air, however, did not gain a secure hold in eastern New England. The maximum at Caribou was only 84° and at Nantucket the top figure was 86° on the hottest day. Though Boston sweltered for two days with 90° weather, a sea-turn cut short the hold of the heat.

The Delaware Valley bore the brunt of the mid-



June solar onslaught. Philadelphia had 100°, and Deep River, New Jersey, reached 102°, and many communities topped the century mark on the weekend of the 15–16th.

AUDREY—Late on the 24th of June a tropical circulation was reported by a shrimp boat in the Bay of Campeche northwest of Yucatan Peninsula. By noon of the 25th a Navy reconnaissance plane and surface ships indicated that the first hurricane of 1957 had been born. Following a track almost directly north in the congenial climate of a trough, Audrey struck a savage blow at the coastline near the Louisiana-Texas border about 0900 on the 27th.

The eye appears to have passed over Orange, Texas, where a calm was experienced after 0915 CST. A 35-mile diameter center was indicated. Maximum gusts of 100 mph swept Orange and also Lake Charles, Louisiana, on the eastern side of the eye. Barometric readings below 29.00 inches were general in coastal areas; the lowest reported was 28.33 inches at Cameron, Louisiana, where the greatest damage occurred.

Although there was considerable wind damage, the greatest losses were sustained by the extremely high tides associated with the eastern side of Audrey. A record tide of 8.5 feet washed in at Morgan City, Louisiana, and at Cameron Courthouse, the only building in that community above water, the tide reached 10.6 feet above normal. A major disaster occurred in Cameron Parish. Despite the fact that the bulk of the population was evacuated, the loss of life is expected to exceed 325 persons. A Red Cross survey indicated 1282 homes were destroyed in the Texas-Louisiana area, and 22,317 damaged; 1562 other buildings were destroyed, and 8250 damaged. The National Board of Fire Underwriters listed Audrey as Disaster No. 86 of 1957. Already over 62,000 claims totaling over $12.5 million have been filed.

High tides and damage were also reported along the Texas coast to the west of the track. High winds did considerable crop damage in Texas, Louisiana, and Mississippi. Winds of near-hurricane force were experienced in Alabama with several associated tornadoes.

Audrey turned northeastward over northern Louisiana and with diminishing vigor lashed the Tennessee Valley and mid-Mississippi Valley with torrential rains ranging up to 10 inches. Apparently, the storm followed a low pressure trough and recurved northward over West Virginia and Pennsylvania where it joined the pressure system moving eastward. The center regained some of its original intensity and at noon of the 29th was centered in southwestern Quebec with a center pressure of 28.70 inches. Damaging winds whipped all the Northeastern States, Ontario and Quebec.

May (*Continued from page 135*)

nent. It forced a small Gulf low on its southern periphery to move directly eastward, and at the same time prevented any far Western frontal systems from making progress eastward.

The dome of cold air remained in the Hudson Bay area for about 72 hours. Then, for reasons unexplained, it traveled to the southwestward, making a large loop over the middle Missouri Valley on the 5th, recurving eastward on the 6th over northern Arkansas, and reaching the Bermuda area on the 8th. The dominance of the anticyclone while over central United States finally turned the upper winds over Texas from southwest to northwest and shut off the sources of moisture over the sodden fields of Texas and Oklahoma where three rainless days were welcomed on the 5th, 6th and 7th.

A second, weaker anticyclone followed from the Canadian Northwest on the 7th, but lost its identity over the upper Mississippi Valley on the 11th in a confused pressure pattern. A third high pressure area maintained itself over the Northwest Territories and Hudson Bay from the 12th through the 19th; this confined depressions to the United States and supplied impulses of cold air into northern United States behind cold fronts. A severe frost visited the Northeast on the 17th as the existing reservoir of cold air over Hudson Bay was tapped by a deep northwesterly flow.

THE BATTLE LINE—Following the anticyclonic disintegration in the Mississippi Valley on the 8–9th, cyclonic activity took control for more than two weeks and the turbulent conditions of April returned in even greater scope. For the two weeks, 13th through 26th, the temperature distribution maps showed a cold West and a warm East, with the dividing line running northeastward from Oklahoma to the Lower Lakes. Here occurred spectacular weather events such as record floods in Texas and Oklahoma, severe tornadoes in Kansas and Missouri, cloudbursts in Minnesota, and very heavy spring rains in Tennessee and Kentucky.

FLOODS—As the month opened shower activity, which had sent many Texas and Oklahoma streams over their banks in April, continued with the result that most streams emptying into the west Gulf were maintaining high flows. The Red and Sabine rivers were near their second highest crests of record. A short respite from these levels followed early in the second week as the brief anticyclonic period brought sunny skies.

The rains resumed, however, after the 10th and became excessive about mid-month. Constant showers and thunderstorms on the 16th to 18th resulted in the Cimarron and its tributaries exceeding the stages of 1926 and 1935. At Hennessy, Oklahoma, a downpour of 13.07 inches fell in 24 hours on the 15th, and there were unofficial figures as high as 20 inches.

The period of excesive rains reached a climax in Oklahoma on the night of 24 May when over six inches fell over a large area of the Arkansas River watershed. By the 27th the entire valley below Tulsa had a major flood. Downstream from Fort Smith it was the worst flood since the memorable stage of 1945.

In Texas, too, heavy rains continued especially in the Dallas area which had its wettest May on record following a very wet April. The Trinity River there crested at 13 feet above flood stage on the 26th, the highest point reached during this year's April–May rains. Flood conditions also developed in Tennessee and Indiana as the atmosphere overturned all along the air mass boundary.

Statement (*Continued from cover 2*)

for that same period with some skill. However, the present status of meteorology does not permit a forecaster to specify day-by-day variations in the weather any more than one week in advance.

Forecasts for periods of more than a month in advance are sometimes attempted. These may say, for example, that the next season will have abnormally high (or low) temperature or precipitation. The success of this type of forecast has not yet been demonstrated and at the moment such forecasts must be considered as experimental.

The position of the American Meteorological Society is that individuals or organizations that publish forecasts for conditions more than one month in advance mislead the public if they do not clearly describe the forecasts as experimental and of unproven value. Furthermore, the Society holds that the issuance of detailed day-by-day weather forecasts for more than two or three days in advance is misleading and is not justified by present meteorological knowledge.

The issuance of any acceptable day-by-day forecasts requires access to large amounts of data usually obtained on nation-wide teletype and facsimile weather circuits. Proper interpretation of such reports requires professionally trained personnel. The American Meteorological Society recommends that all regular forecasting personnel should possess training or qualifications at least equivalent to those considered a minimum for professional membership in the Society.

Hurricanes and Tropical Storms

(*Continued from page 133*)

(8) Oct. 4, 1949, Freeport, Tex.; storm tide exceeded 11 feet at Freeport; $5,000,000 damage to Texas rice crop.

Storms in other areas have resulted in large numbers of deaths due to drowning. Notable examples are:

(1) Sept. 16, 1928, over 1,800 deaths due to wind-driven waters in Lake Okeechobee, Fla., area.

(2) Sept. 2, 1935, Florida Keys; storm wave estimated to be 15 to 20 feet above mean low water; nearly 400 persons killed.

(3) Sept. 21, 1938, New England; 600 persons killed in this severe hurricane which was accompanied by high tides, heavy seas, and hurricane winds.

(4) Oct. 7, 1737, Bay of Bengal; storm wave rose 40 feet (in this area the shape of the coast is conducive to amplified storm surges); 300,000 persons perished in lower Bengal or in the bay.

Rainstorm (*Continued from page 131*)

on the 5th, 5,080 cu. ft. per second. This gage is unaffected by tidal rise in Potomac water. The Rock Creek gage, at Sherrill Drive in Rock Creek Park near the Maryland line, rose 1.3 feet between 1800 and 2100 and registered 2 feet by early morning of the 5th. This gage was located near the center of highest intensity, where the rain was prolonged for an hour or two as the cold front passed after the intense downpour accompanying the squall passage. This accounts for the rise between 0100 and 0400 following a drop after the heavy rain ceased at 2100. Mean discharge at this gage increased 119 cu. ft. per second after the storm.

Storm Damage

Storm-clogged sewers, paralyzed traffic, leaking roofs, and rain-filled cellars caused thousands of dollars worth of property damage. The District engineer, responsible for studying means of handling such a deluge of water, requested use of the figures on intensity herein compiled to incorporate in an annual report on sewer facilities.

From the viewpoint of defense of the District in wartime, it is interesting to consider the effect of such a storm if immediate evacuation of population or storage and movement of materiel were involved.

Data

Official Signal Corps and Weather Bureau rainfall observations were examined from 1870 to date. Before that the Smithsonian Institution and Office of the Surgeon General's records from 1848 to 1870 were searched for excessive rainfall data. A card file of severe historical rains and floods compiled in 1936–1938 by the Soil Erosion History Project of the Soil Conservation Service was of special benefit in corroborating the early Smithsonian records. In 1939, so far as records and documents up to that time could corroborate, no storm had intensities equal to this for the 5-minute and 120-minute intervals. Weather Bureau records from 1939 to date were examined recently to establish the storm's identification as a "once-in-a-hundred-year" rainstorm.

Forecasting (*Continued from page 120*)

employing vorticity concepts were developed as early as the late 1930's and used for many years in extended forecasting work, it is only in the past five years or so that these concepts have filtered generally into short-range prognosis. Now, thanks to numerical weather prediction, the direction of flux of knowledge regarding prediction is reversing so that gains in short-range work are playing a more active role in helping extended forecasting.

The Meso-Scale

A few words regarding the meso-scale part of the forecasting spectrum: Great advances have been made indicating ability to predict severe storms and squall lines with much more precision than thought possible in earlier years. Estimates of local rainfall, pollution concentration, and such things are routine. And in this particular scale we must not forget airways forecasts. Although dedicated airways forecasters rarely break into the headlines, they have nevertheless developed valuable skill in predicting terminal weather, upper-air winds, and numerous other elements important to a rapidly expanding aviation. Looking back on a brief career as an airways forecaster some 25 years ago, I marvel at the specific nature of predictions of this sort now being made. It is indeed likely that because of his great familiarity with detailed weather, he may play an increasingly important role in forecasting with the help of guidance material supplied by numerical analyses and prognoses. He may, in fact, become the closest approach to being the "weather man" of tomorrow.

Some Shortcomings

No survey can be complete without some comment regarding deficiencies or shortcomings which forecasting must overcome. Obviously, the future depends to some extent upon the degree to which we overcome these deficiencies. In the first place, there exists a lack of faith of weather forecasters in each other. In the old days each man wanted to plot his own weather map. In this way it was "done right," and besides he felt it necessary to catch up with the weather. After this inefficient procedure was abandoned many meteorologists felt that they had to do their own analysis in order to make weather forecasts and could not depend on anyone else's. There are now only a few hold-outs for this outmoded custom. But a new problem is arising: The regional expert often thinks that he can best handle all problems relating to his area, whether they be airways, 24-hour, 48-hour, 5-day, 30-day, or beyond. He wants to make any and all predictions pertaining to his domain. In reality, he may not have the kind and quantity of data necessary to make such predictions. For 48- or 72-hour predictions, for example, nothing short of entire hemispheric coverage is sufficient. There is a natural and to some extent justifiable feeling among local forecasters that they can do a better job for their particular area by virtue of their intimacy. Ultimately, we hope all forecasting will be handled so that the local skills play an important role—certainly this is the trend. But it seems high time that the forecasting profession realizes that it now has specialists, not only areally but equally important in terms of the time scale of the phenomena to be predicted. Hence the local man must rely on broad-scale and extended-time scale prognoses for his major background material. Similarly, large-scale or extended range forecasters should not try to satisfy requests for detailed predictions such as airways forecasts.

A second deficiency involves misguided attempts by detractors to ascribe the success of the other fellow's forecast to some simple statistical procedure, ignoring any physical considerations used in the methods. The idea here is apparently to set up a simple yardstick to pit the forecast or physical method against. Certainly, this is an administratively justified procedure often necessary in making decisions involving manpower and expenditure, but it often has little to do with testing the proposed idea or, more important, leading to its further development. For example, in numerical forecasting we want to find out, firstly, its effectiveness, not related to a "birdshot" type system of prediction, but in terms of how the models predict the behavior of the atmosphere. Statistical controls, when properly employed, can be very helpful in doing this.

A deficiency of major proportions is our lack of sufficient systematic study of errors

in numerical forecasts. At times it almost appears that there is a lack of concern for this problem among individuals at installations where research on numerical weather prediction is performed. By now it should be quite clear that the elimination of errors of numerical prediction is not entirely a matter of inserting terms left out of the equations of motion. It is necessary, as it has always been in the history of weather forecasting, to study the atmosphere in terms of how she solves her own equations. However, more often than not the tendency is for the dynamic meteorologist to shun empirical work of this nature and to let it fall into the hands of people who, although well qualified in statistics, may not be sufficiently qualified in meteorological physics or synoptics.

Finally, there is still not adequate communication between researchers and forecasters. The subject of numerical forecasting stripped to its essence must be clarified to the user of the prognostic charts at field stations. Only with reasonable understanding can he suggest improvements or use them most effectively.

The Future

So much for survey. As to outlook, the rapid pace of developments and requirements makes predictions almost as difficult to make as weather forecasts. My opinion is that numerical upper-level forecasts will gradually improve to such a degree that it will soon be folly for the human forecaster to compete or try to improve upon them at intervals beyond 48 hours. Perhaps this state has already been reached for 48-hour forecasts. Improvements will come about first through an expanded grid and by semi-empirical studies of error fields. These studies will, in turn, lead to better physical understanding so that improved physical models will result. I believe that numerical weather prognosis will gradually catch up with and replace conventional methods of prognosticating the sea level map. This will require more organized collaboration on the part of the conventional forecaster, who must first make more use of numerical upper-air predictions to improve his sea level prognosis and then help introduce the methods in an objective fashion for

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machine calculation. In a sense the conventional forecaster's aim and responsibility are to assist in replacing part of his talents by automation, thereby redirecting his efforts to the weather problem on a local or regional scale.

In extended forecasting up to periods of a week experiments currently being made suggest that also in this field the prediction of upper-level wind patterns in the mean and for individual days within the period will be done electronically. The accent for some time to come will be on broad-scale patterns and trends, but increasing ability to predict detail in space and time up to about a week should come fairly rapidly. Instead of predicting a mean for, let us say, 5 days, the probability is that overlapping 5-day mean charts a day apart for several days in advance, an "evolving mean," will provide a sound basis for obtaining the day-to-day maps by inverse smoothing procedures.

The broad-scale weather picture, particularly for temperature and precipitation, should receive a more satisfactory solution than at present through better understanding of the relationship of flow pattern to weather and through incorporation of these results numerically—although for several years the broad-scale weather problem will probably be best handled by synoptic and statistical methods.

In longer period (30-day) forecasting, the prediction of upper-air patterns will be greatly facilitated by electronic computations, although the "models" employed will be partly statistical and partly dynamic. For several years statistics should perform a necessary function in serving as substitutes for important knowledge of such factors as non-adiabatic heating, friction, etc. After dynamic meteorologists have been convinced of the general success obtainable even with crude estimates of such terms, they may be able to formulate realistic physical models—an achievement which will mark a breakthrough perhaps ever more far-reaching than that in short-range prediction. The undeniable objectivity of a machine-made prognosis is so much more compelling of respect than ordinary synoptic studies and forecasting performance that the first stages of statistical-dynamic prediction are very important for the future development of long-range forecasting.

In the field of still longer range prediction of the order of a season, a year, or a decade, a cautious optimism seems justified. This does not result from a system of long-range forecasting presently in use or even on the drawing boards. Rather, it is based on the fact that the masses of data which are now being assembled and processed can be fed into machines at fantastic rates, so that the statistical properties of long period circulations should be fairly well exhausted after about a decade. These studies in themselves will provide at best broad probabilities—a substantial advance over the present day's climatological estimates. But they may bring to light factors relating to persistence and lag that could very well lead to fertile ideas and subsequent development of a forecasting method. It would seem likely that general predictions of average weather at least a season in advance with some economic value should be possible within ten years.

Returning to the question of meso-scale predictions, probably the principal role of most practicing weather forecasters of the coming generation, it appears unlikely that problems of this nature will be handled by machine methods for a long time. In the first place, even description and observation of the phenomena are difficult. Careful synoptic studies of this kind are just beginning and the meteorology of small systems has hardly entered the descriptive phase. The development of physical methods will require much more observation, description, and most of all, the contingent understanding. At some point down the scale man may never be able to afford the dense networks required to properly observe, let alone to forecast certain phenomena. Hence, for some time to come it looks like synoptic-statistical methods will underlie the meso-scale forecaster's interpretation of large-scale circulation and weather prognoses furnished by machine.

But glimpsing further into the future, when and if electronic computing machines are almost within the purchasing power of a small community, even the observation of small scale weather and computation of its trend of development and movement may replace the human forecaster. A "human" one, after all, the author confesses a feeling of anticipated nostalgia despite his efforts to help bring about the age of meteorological automation.

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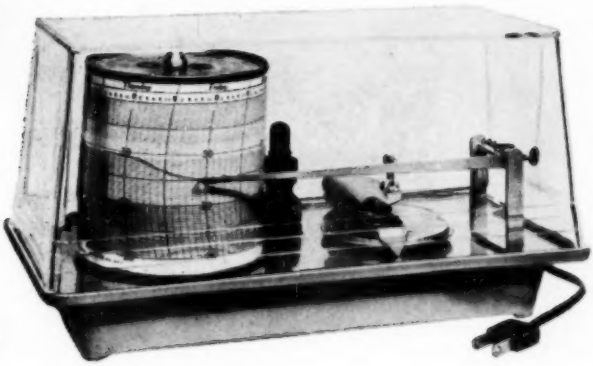

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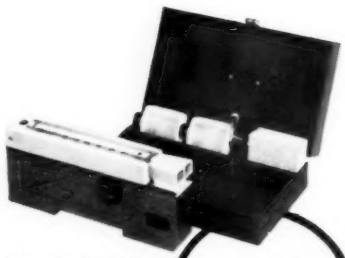

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